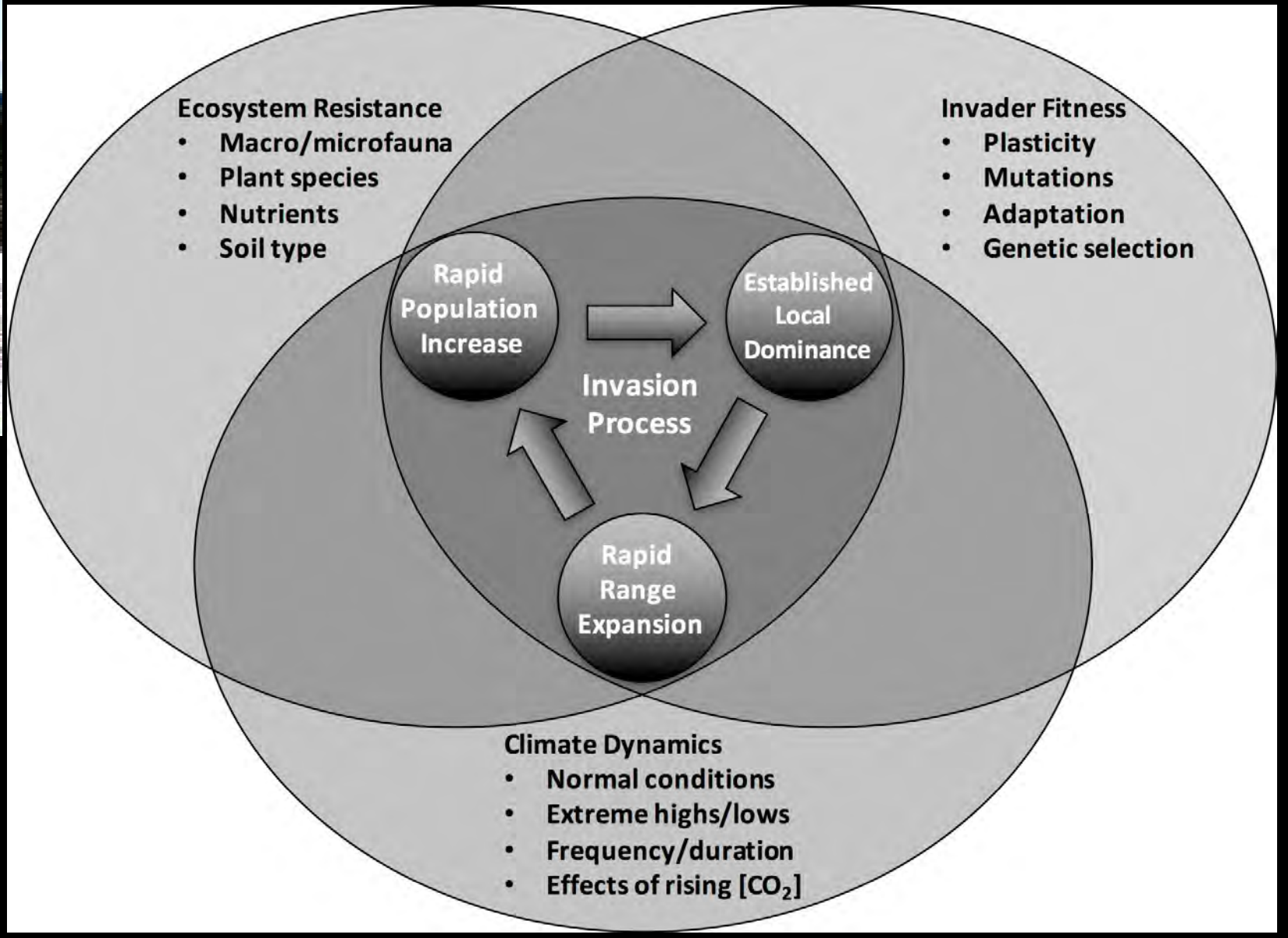
More frequent extreme weather and flooding under climate change as catalysts for invasive plant spread

David R. Clements

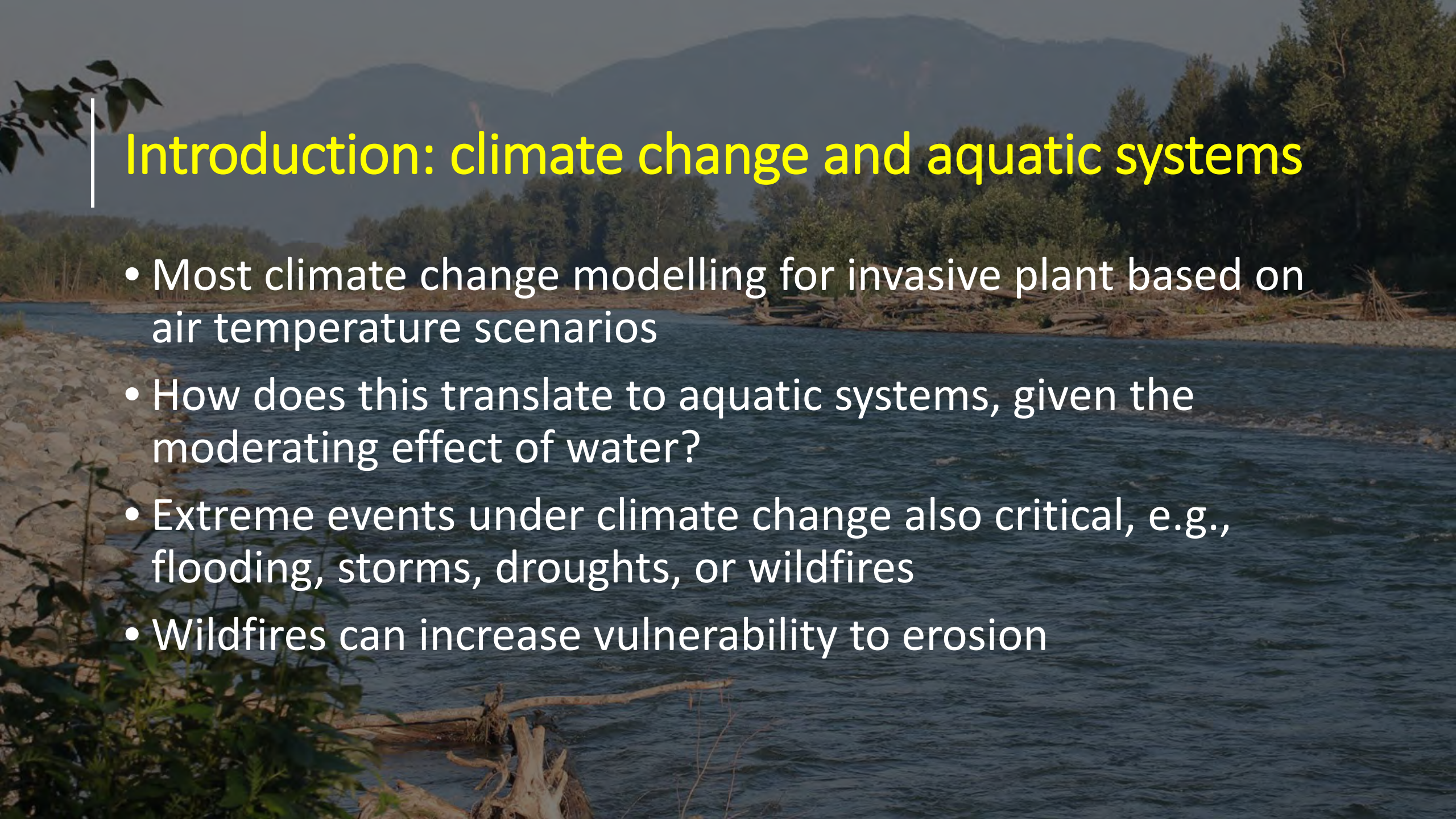
TRINITY WESTERN UNIVERSITY

Steve Young
Utah State University



Toni DiTommaso
Cornell University

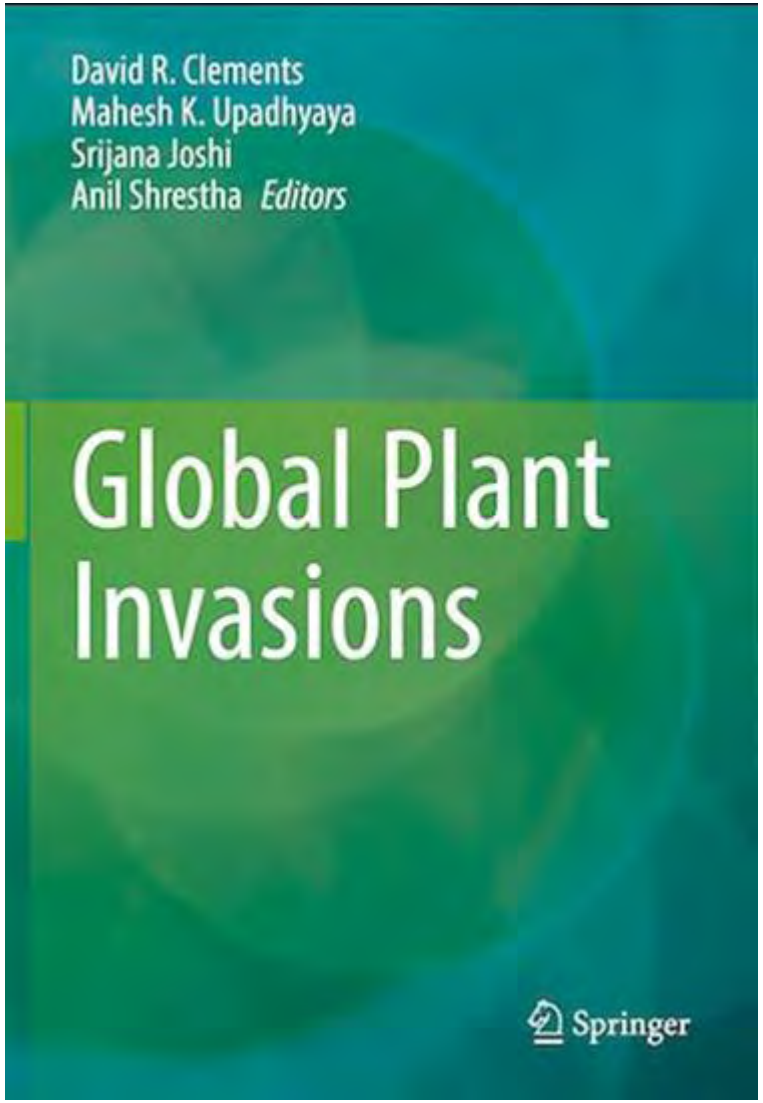
Young SL, Clements DR, DiTommaso A (2017) Climate dynamics, invader fitness, and ecosystem resistance in an invasion-factor framework. *Invasive Plant Science and Management* 10:215-231.

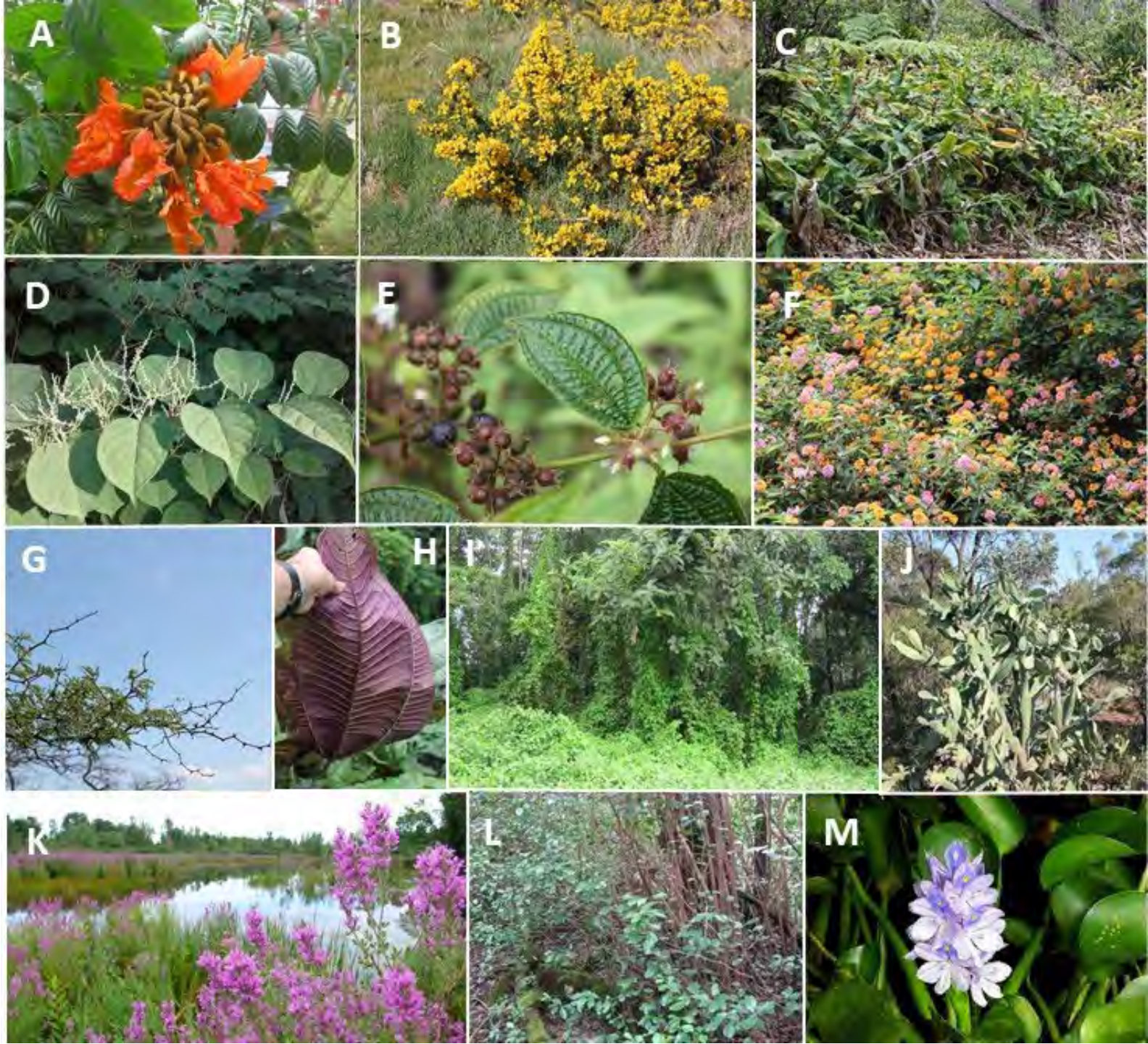


Introduction: climate change and aquatic systems

- Most climate change modelling for invasive plant based on air temperature scenarios
- How does this translate to aquatic systems, given the moderating effect of water?
- Extreme events under climate change also critical, e.g., flooding, storms, droughts, or wildfires
- Wildfires can increase vulnerability to erosion

Plant invasions have “gone global”





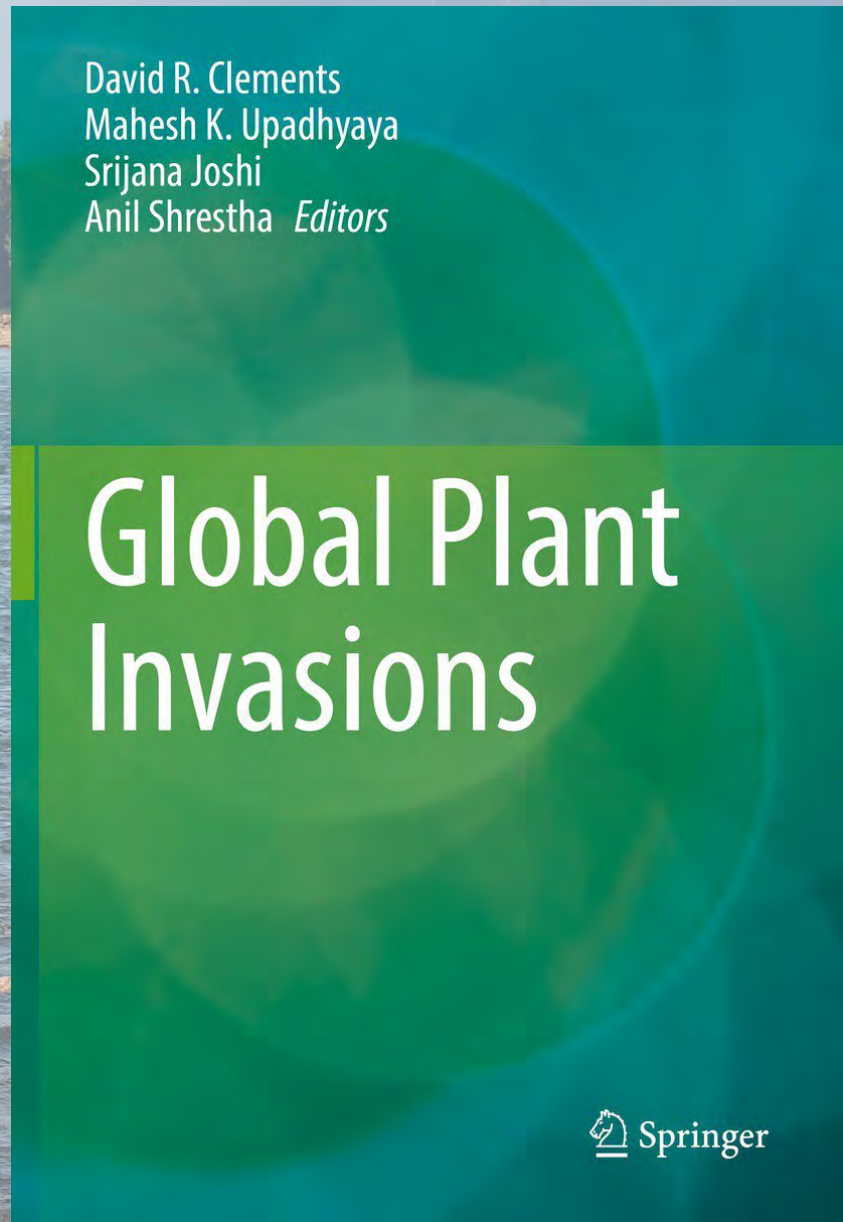
Ziska (2022) review of the effects of rising CO_2 and climate change:

- research predicts poleward spread of invasive species and range expansion in many cases due primarily to warming

Two other major effects:

- plant physiological impacts of higher CO_2 levels
- effects of extreme climate events

Ziska LH (2022) Plant Invasions, Rising CO_2, and Global Climate Change. *Global Plant Invasions*, pp.71-87.



Flooding headlines (Sept. 22, 2023 sample)

Top stories

CNN

Horrific Libya flooding made up to 50 times more likely by planet-warming pollution,...

3 days ago

PHYS.ORG

As extreme downpours trigger flooding around the world, scientists take a...

3 days ago

NBC NEWS

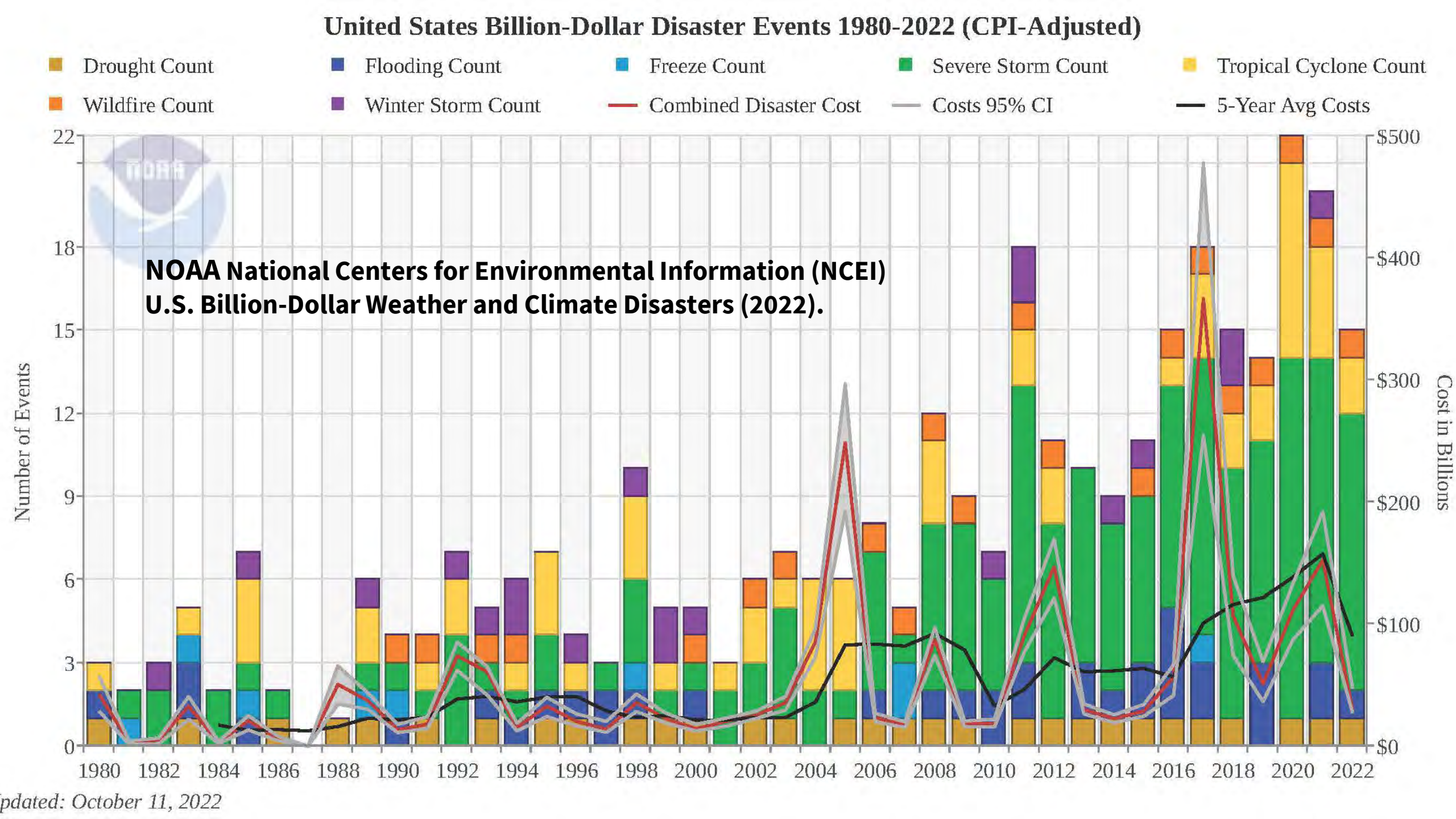
Eight catastrophic floods in 11 days: What's behind intense rainfall around the...

1 week ago

Al Jazeera

Photos: Hong Kong paralysed by extreme floods from Typhoon Haikui

2 weeks ago


United States Billion-Dollar Disaster Events 1980-2022 (CPI-Adjusted)
Drought Count
Flooding Count
Freeze Count
Severe Storm Count
Tropical Cyclone Count
Wildfire Count
Winter Storm Count
Combined Disaster Cost
Costs 95% CI
5-Year Avg Costs
NOAA National Centers for Environmental Information (NCEI)
U.S. Billion-Dollar Weather and Climate Disasters (2022).
Number of Events
Cost in Billions
0
3
6
9
12
15
18
22
$0
$100
$200
$300
$400
$500
1980
1982
1984
1986
1988
1990
1992
1994
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1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
pdated: October 11, 2022

Bedford, Nova Scotia,
July 22, 2023
“three months of rain in less than 24 hours”

Source: Reuters

Montpelier, Vermont July 11, 2023
Received a record 13.41 cm on July 10
Previous record of 13.38 cm in 2011 due to Hurricane Irene

Source: CNN

Tropical Storm Irene in Vermont (2011)

Brian Colleran, knotweed program in Vermont (Daily Herald)

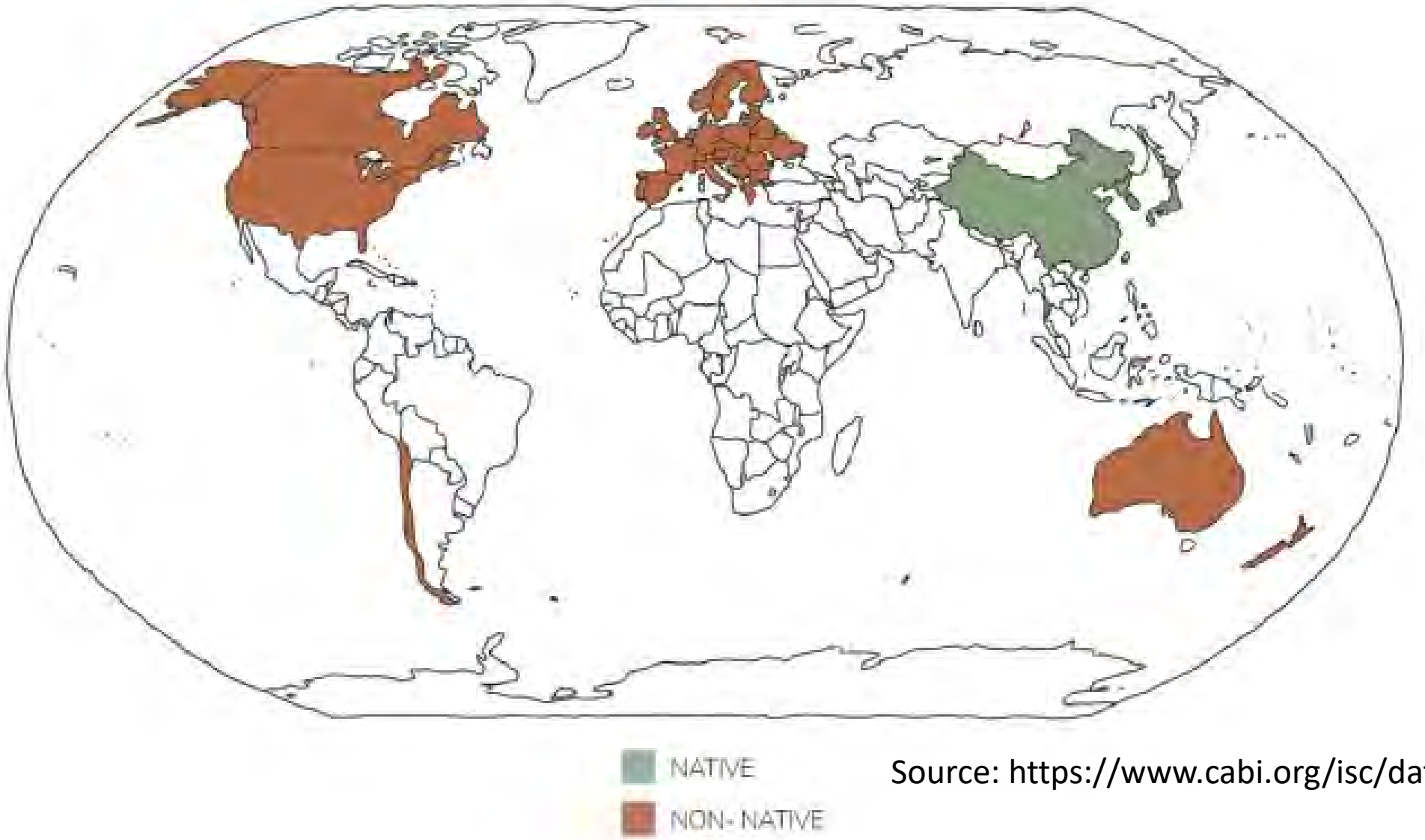
- “the floodwaters from Tropical Storm Irene and work afterward to dredge rivers and remove debris spread fragments of Japanese knotweed, a plant that threatens to take over flood plains wiped clean by the August storm”
- Colleran & Goodall (2015) *Invasive Plant Sci Manag*

Drivers of plant invasion

Various mechanisms enable weeds to adapt to the pressures of climate change (Clements & Jones 2021; *Agronomy*)

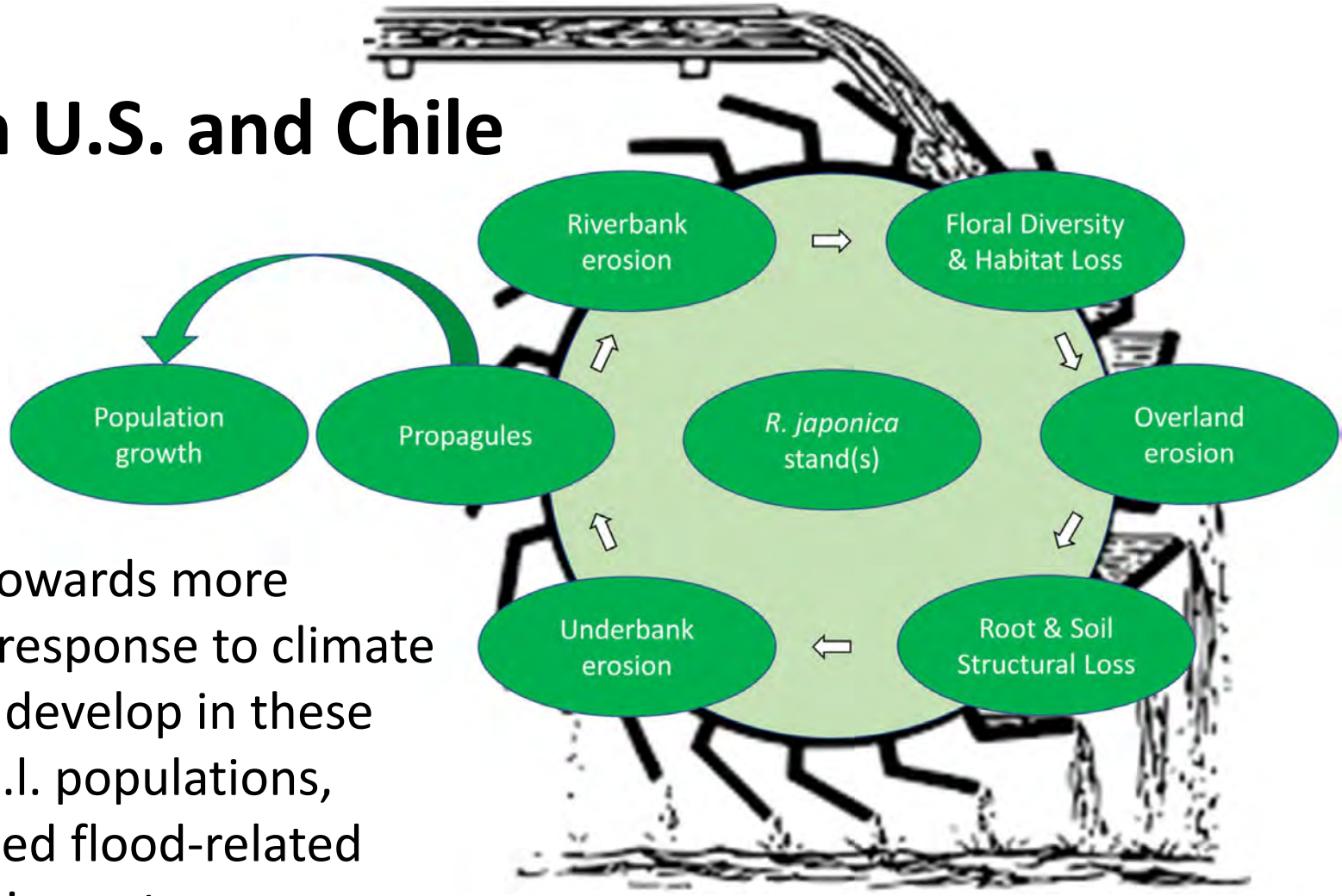
Vanessa Jones

World distribution of knotweed spp.



Source: https://www.cabi.org/isc/datasheet/23875

Eastern U.S. and Chile



"As some hydrological regimes shift towards more frequent and severe storm events in response to climate change, positive feedback loops may develop in these regions between existing knotweed s.l. populations, sudden riverbank failure, and increased flood-related damage, with presumably significant impacts on riparian infrastructure."

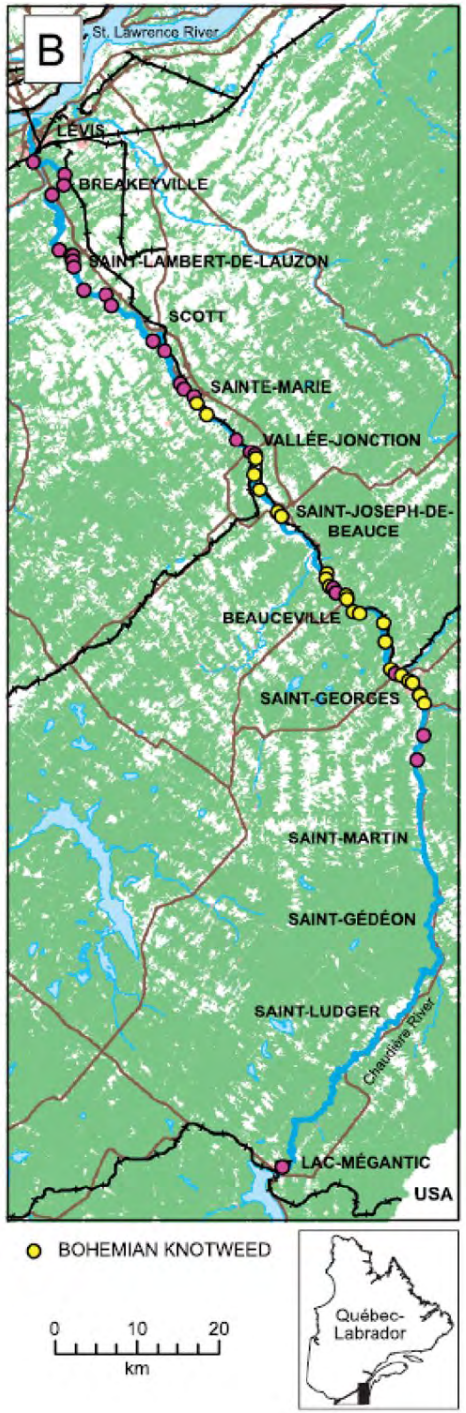
Brian Colleran, Shaw Nozaki Lacy, and Maria Rafaela Retamal (2020) Invasive Japanese knotweed (*Reynoutria japonica* Houtt.) and related knotweeds as catalysts for streambank Erosion. *River Res Appl*

Knotweed vs. Québec watersheds

Claude Lavoie, Université Laval

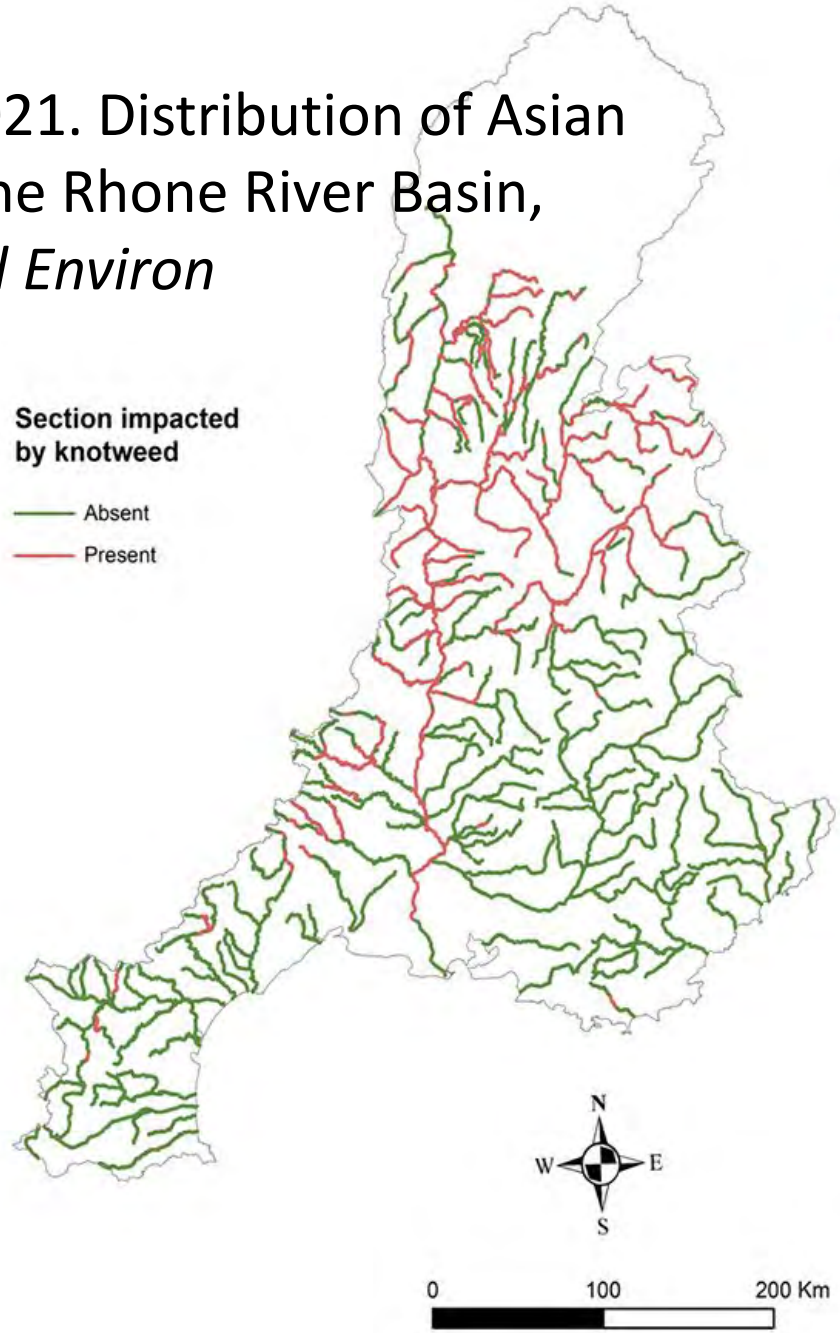
- Knotweed spread through much of Chaudière River in Québec from urban centers by flooding
- Etchemin River study showed removing small shoots immediately after flooding could be effective but not economical for larger infestations

Duquette et al. (2016) *River Res Appl*;
Rouleau et al. (2023) *Invasive Plant Sci Manag*



France

Navratil et al. 2021. Distribution of Asian knotweeds on the Rhone River Basin, France…*Sci Total Environ*



Dispersal

floods

bank erosion

river connectivity

Plant introduction

roads and railways

social representations

management policy

Implantation

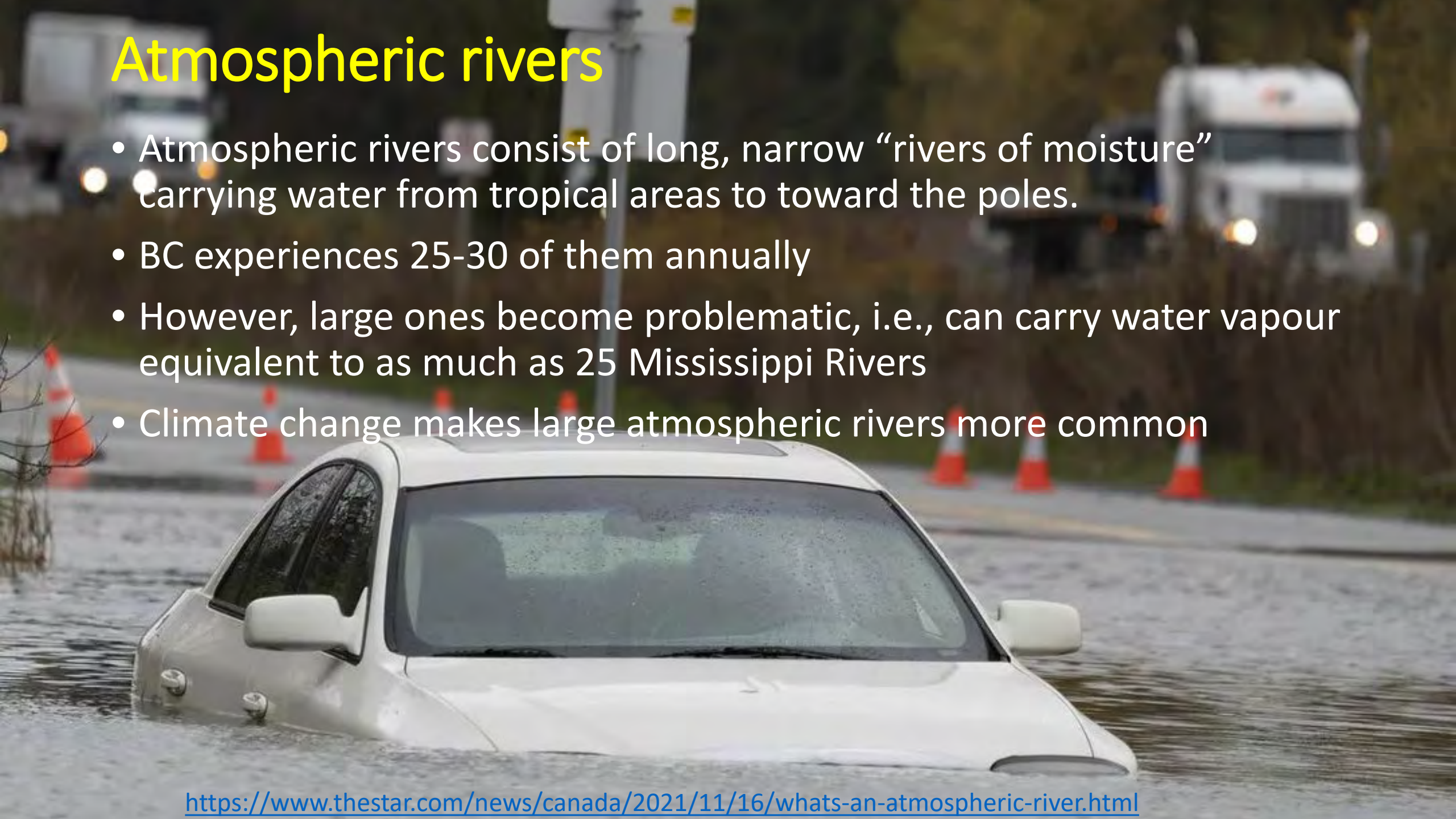
spring rainfall

hydraulic infrastructures

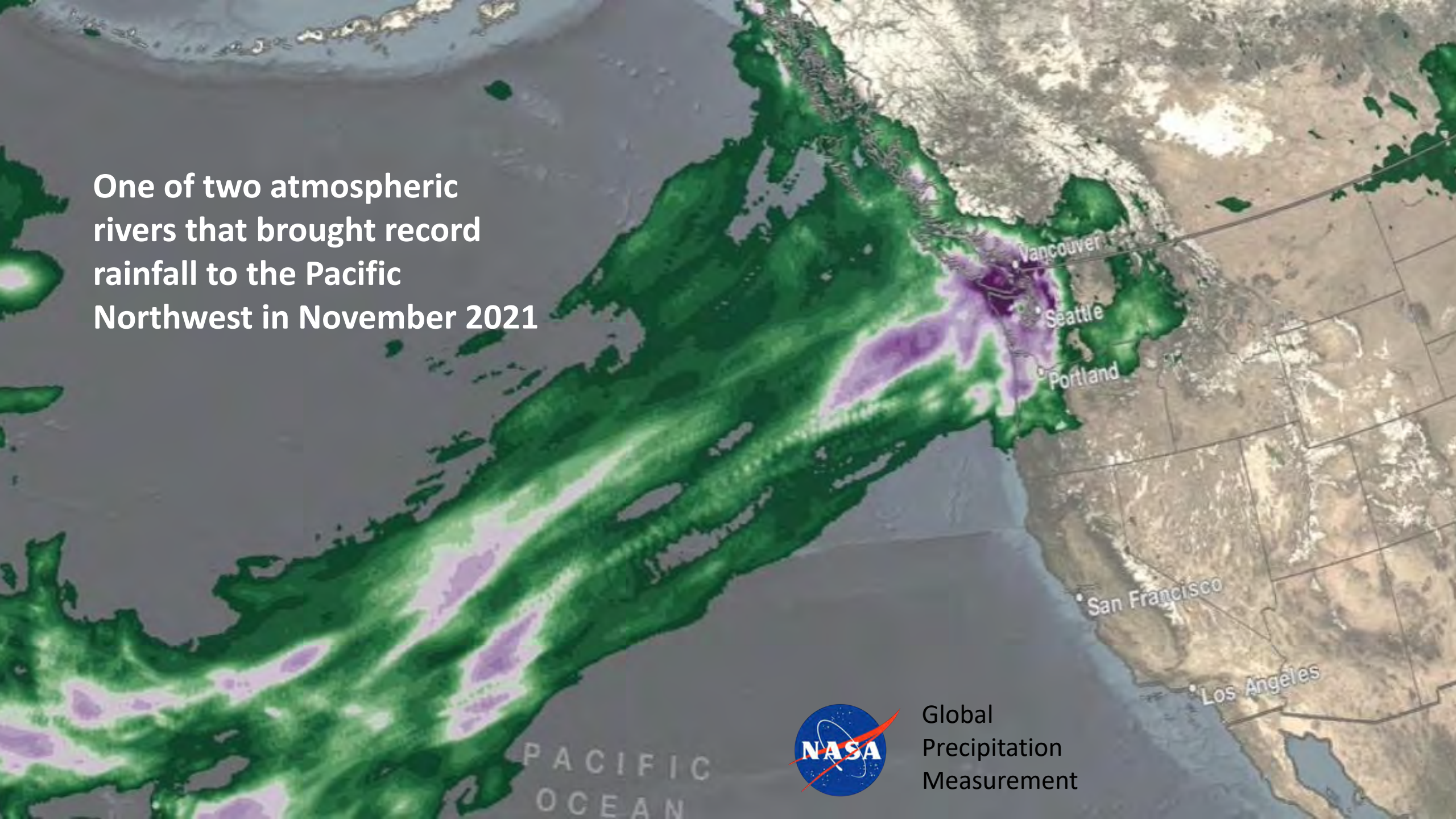
riparian forest

Atmospheric rivers

- Atmospheric rivers consist of long, narrow “rivers of moisture” carrying water from tropical areas to toward the poles.
- BC experiences 25-30 of them annually
- However, large ones become problematic, i.e., can carry water vapour equivalent to as much as 25 Mississippi Rivers
- Climate change makes large atmospheric rivers more common

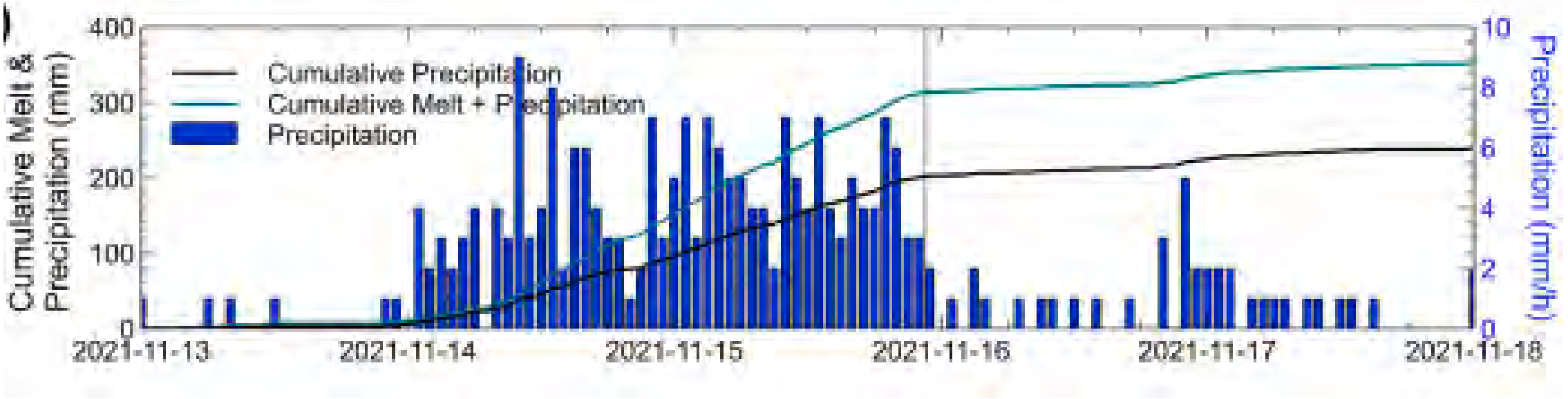


https://www.thestar.com/news/canada/2021/11/16/whats-an-atmospheric-river.html


One of two atmospheric rivers that brought record rainfall to the Pacific Northwest in November 2021
Vancouver
Seattle
Portland
San Francisco
Los Angeles
PACIFIC OCEAN
NASA
Global Precipitation Measurement


Fraser Valley Flooding, November 2021
Ben Nelms/CBC)

Unprecedented rainfall levels



Rainfall in the Chilliwack Basin, British Columbia, Canada for 13-18 November 2021 lead to discharge of over 700m^3s^{-1}, over ten times the mean discharge

Chilliwack-Vedder River November 2021

Chilliwack-Vedder River November 2021

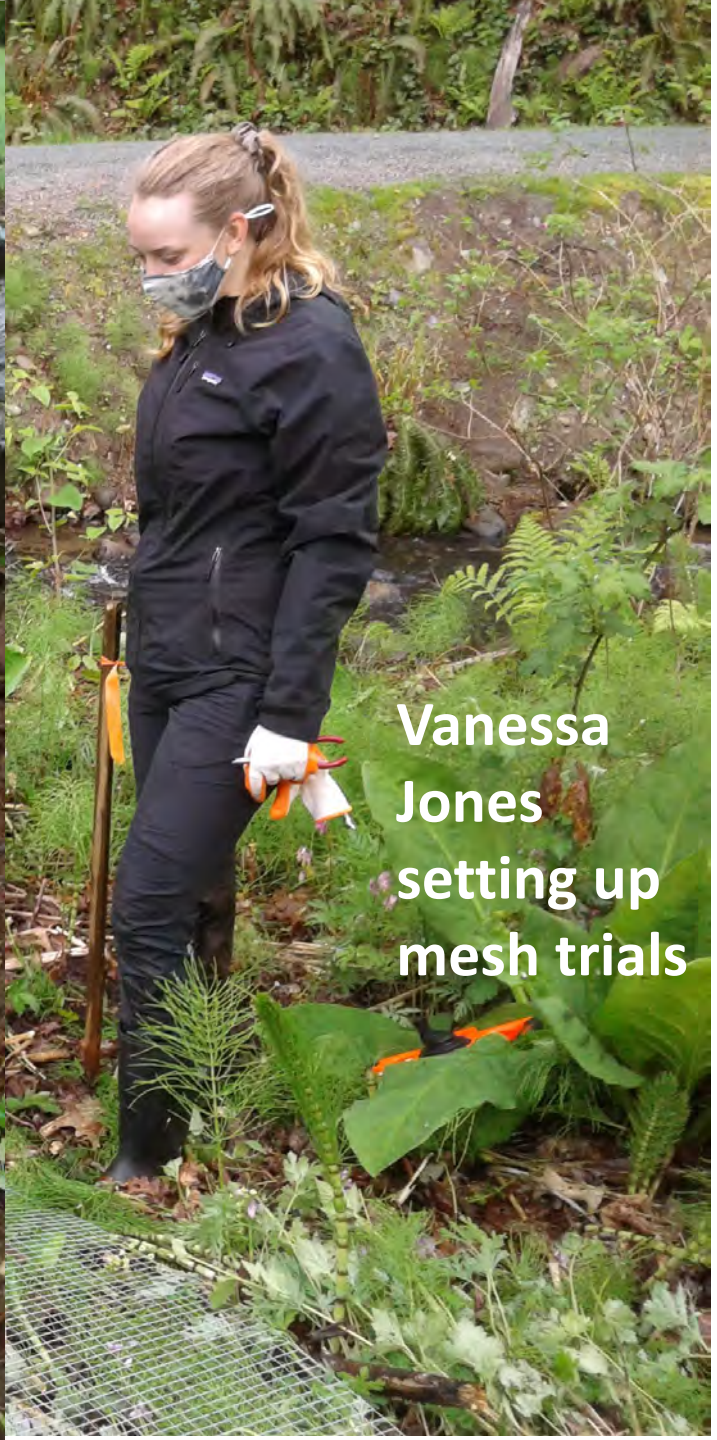
Chilliwack-Vedder River 2021 & 2022

Knotweeds (*Reynoutria* spp. and climate change)

Features that promote spread of knotweeds via flooding:

- Rapid growth rates
- Optimized growth and reproduction near water
- Extensive underground rhizome networks
- Ability to disperse via seeds and rhizomes
- Difficult to control, especially with herbicide restrictions near water

Jennifer Grenz Injecting knotweed with herbicide



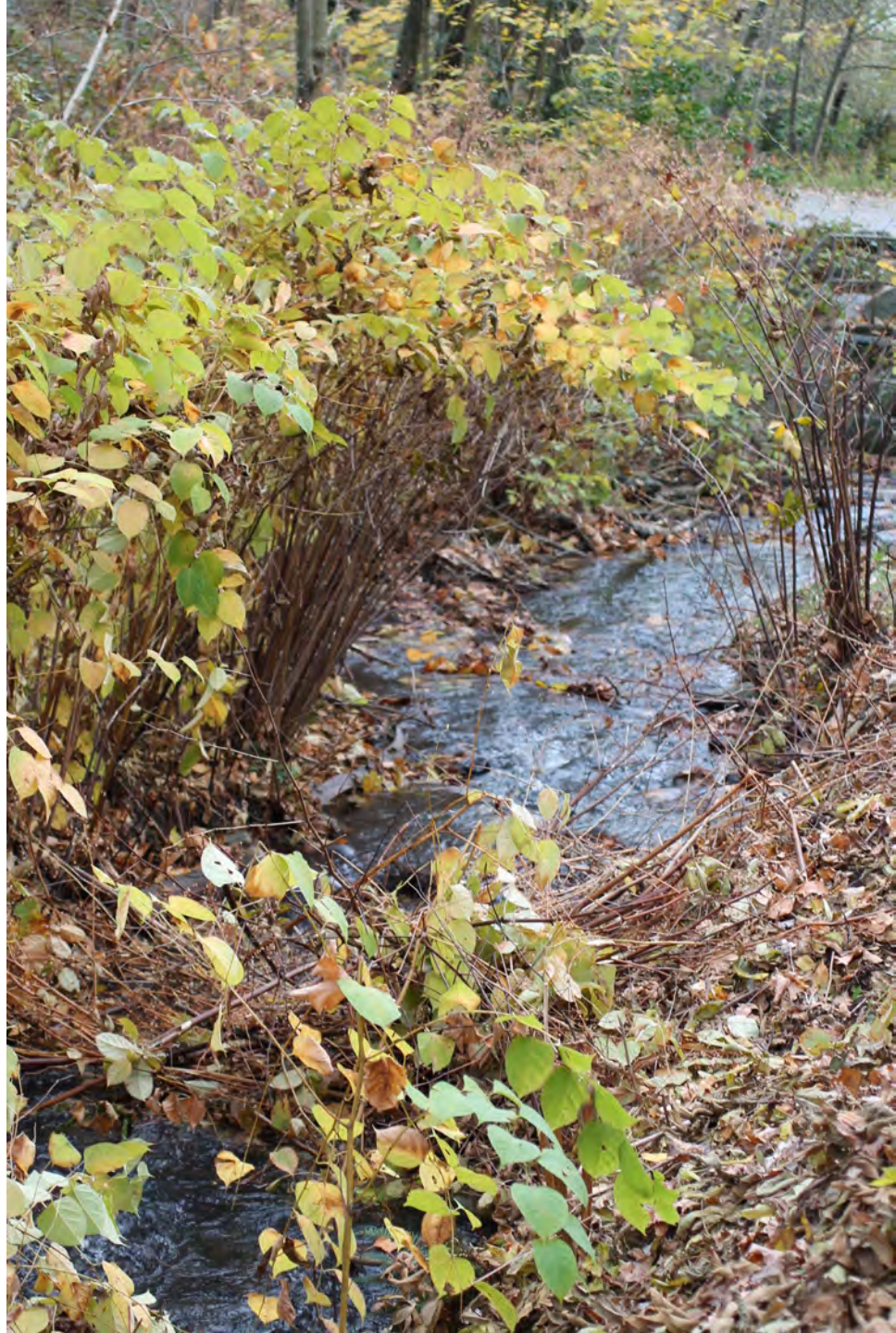
Vanessa Jones setting up mesh trials

Research students Maria Goncharova, Hannah Munnalall and Virginia Oeggerli at a knotweed patch

Research students Aidan Anderson, Maria Goncharova, and Hannah Munnalall with a knotweed rhizome

Knotweed seed biophysics

- larger wings on seeds = higher floatation ability and seed trait variation may be key to evolutionary ecology of *R*. × *bohemica* (Lamberti-Raverot et al. 2017, *Flora*)



Seedling dynamics in water

Step 1: Sinking 3.3-4 days*

Step 2: Germinating 5 days regardless of current

Step 3: Exhibiting cotyledons 9.2-15.6 days

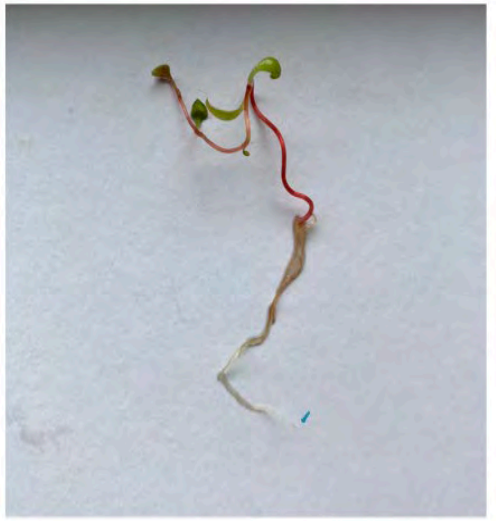
Step 4: Exhibiting true leaves 27.3-28.3 days

Step 5: Withering (mortality) 42.7-51.4 days

**experiments employed 3 turbulence levels; variation reflects different responses to current*

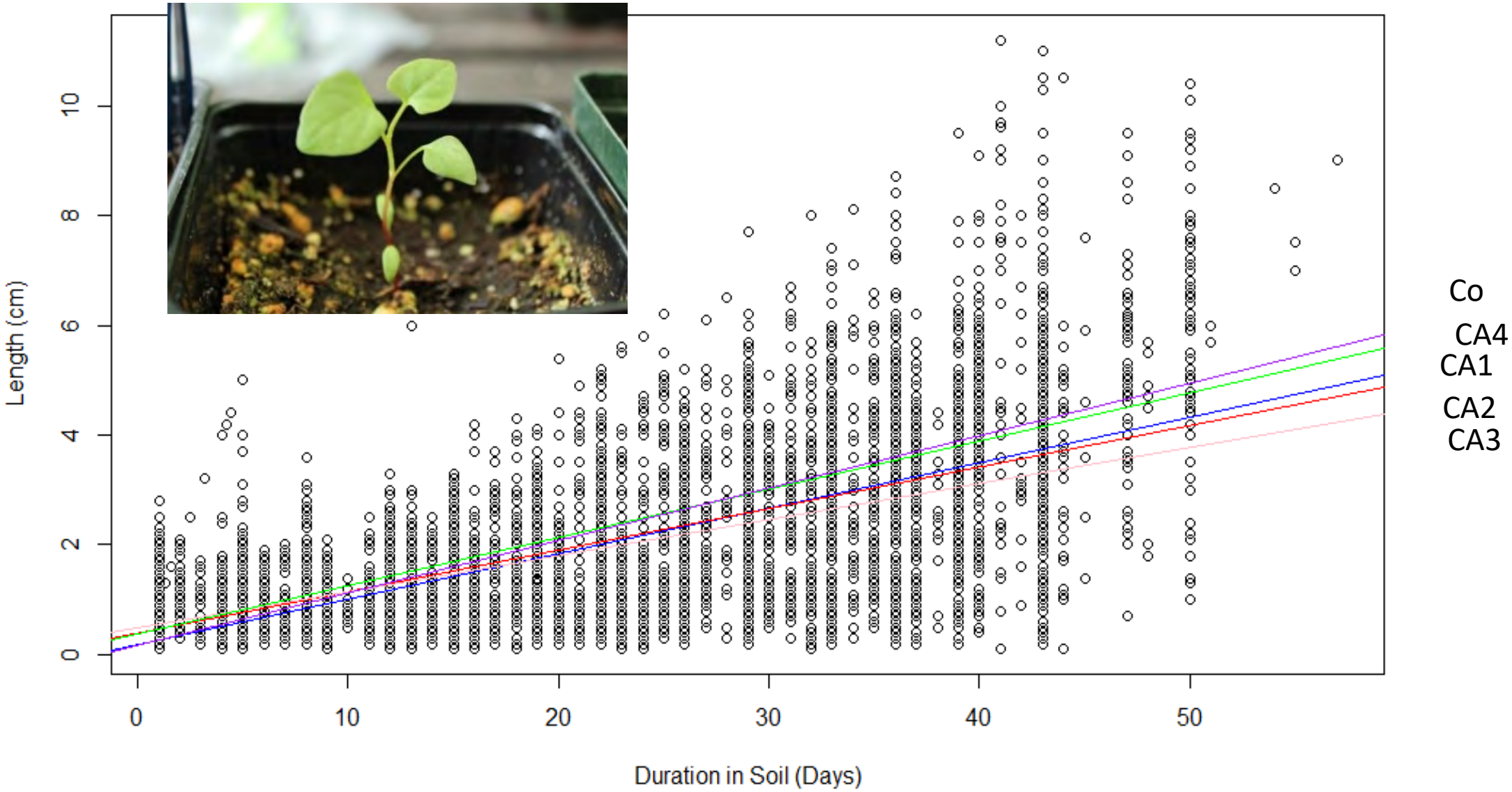
Germinating

Exhibiting cotyledons



Exhibiting true leaves

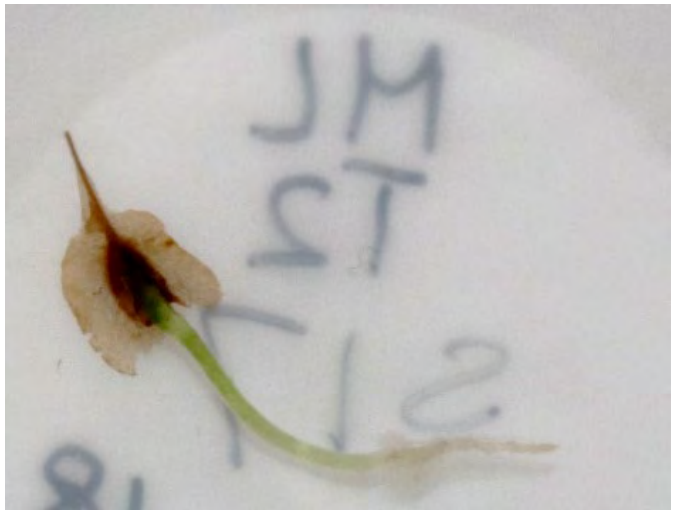
Withering



Average *Reynoutria* × *bohemica* seedling growth rate in soil with respect to current treatments control (C0, no water treatment), no (CA1, 0 m s^{-1}), low (CA2, 0.05 m $^{-1}$), medium (CA3, 0.1 m s^{-1}) and high (CA4, 0.3 m s^{-1}).

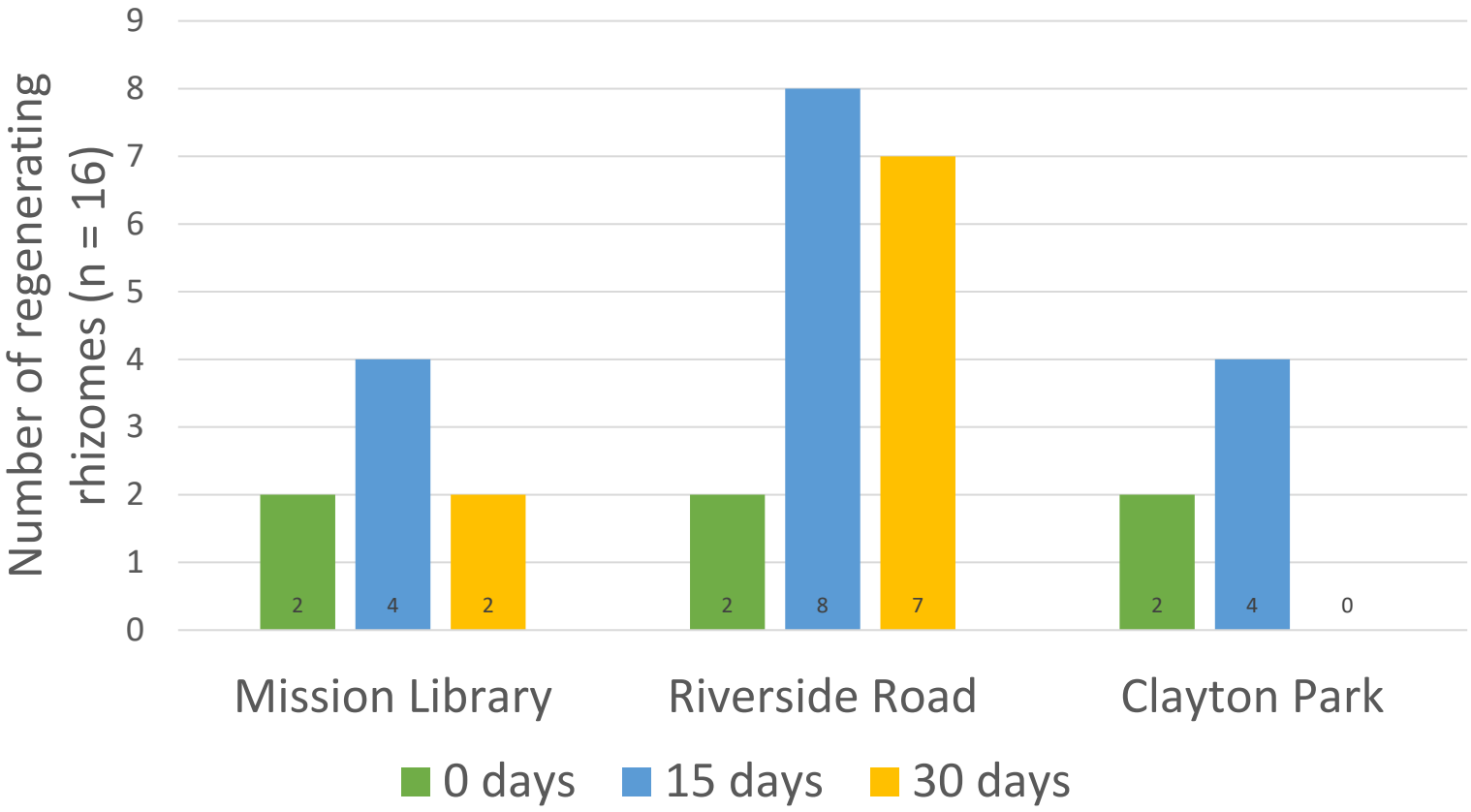
River dispersal modes

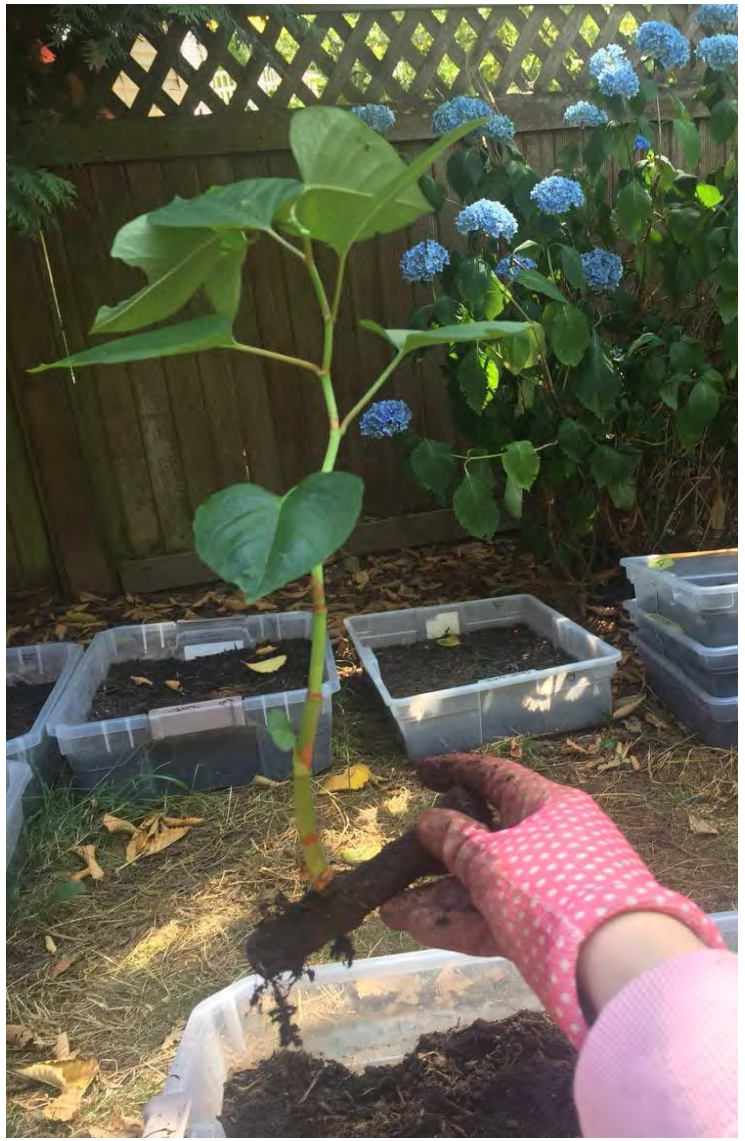
- Knotweed uses watersheds to disperse via seeds, stem fragments or rhizomes
- Rhizome fragments = most effective



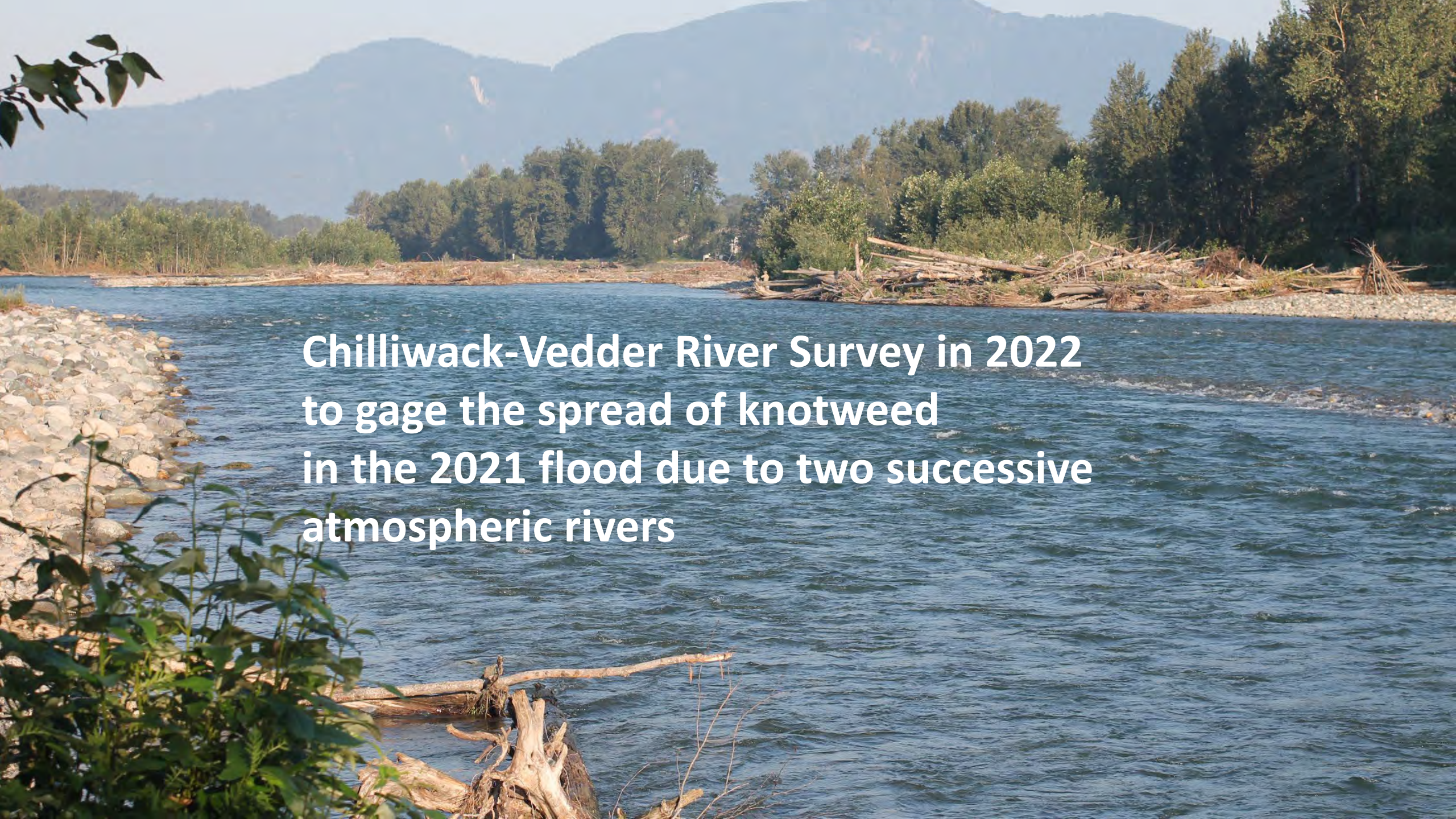
Jaylene Braithwaite shows seedling growing from a rhizome fragment spread via a flooded river in Chilliwack, BC, Canada

Regeneration from rhizomes increased by immersion in water





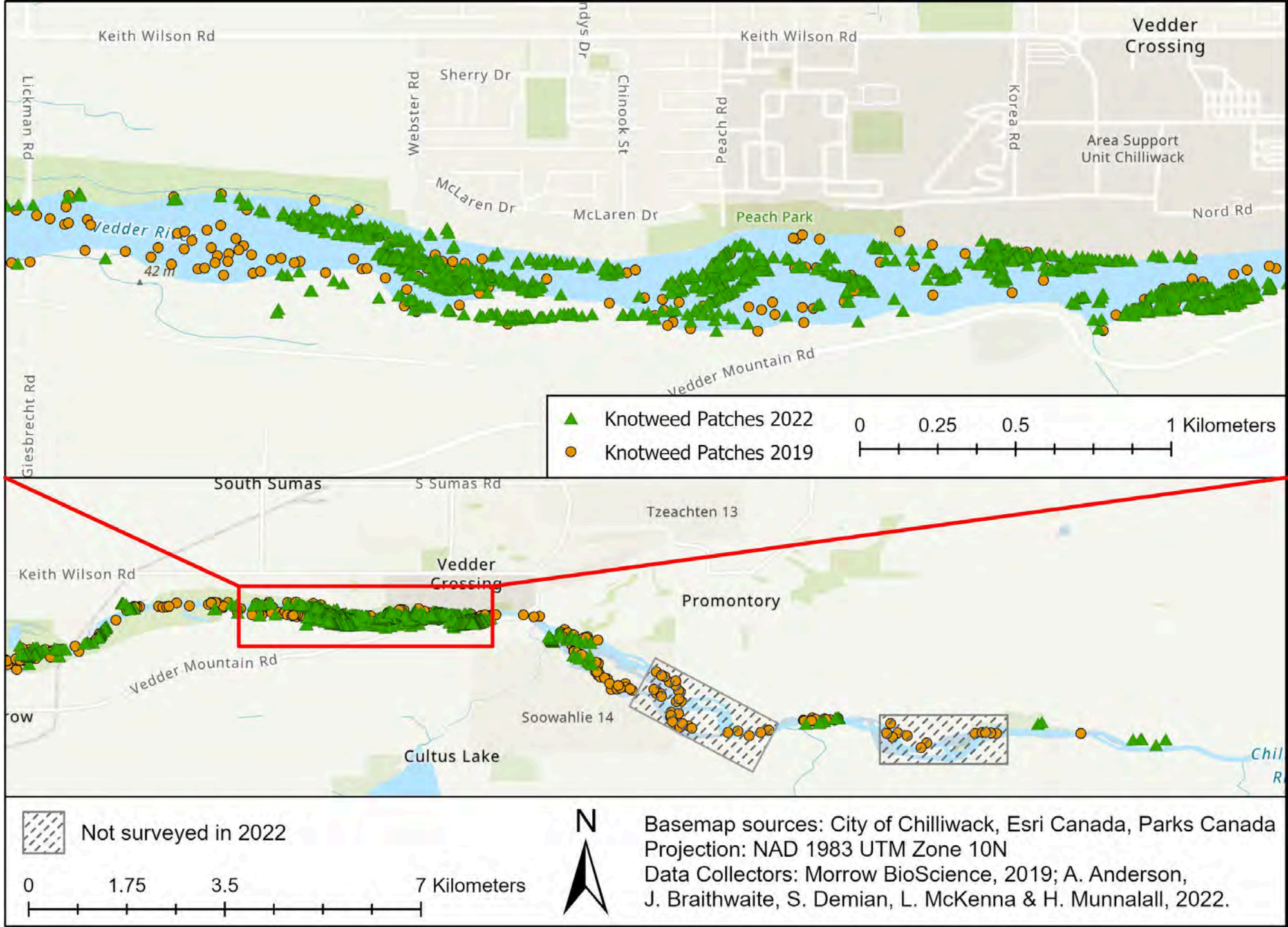
100-year flood event in the Fraser Valley
Costliest natural disaster in British Columbia history
November 23, 2021
THE CANADIAN PRESS/Jonathan Hayward

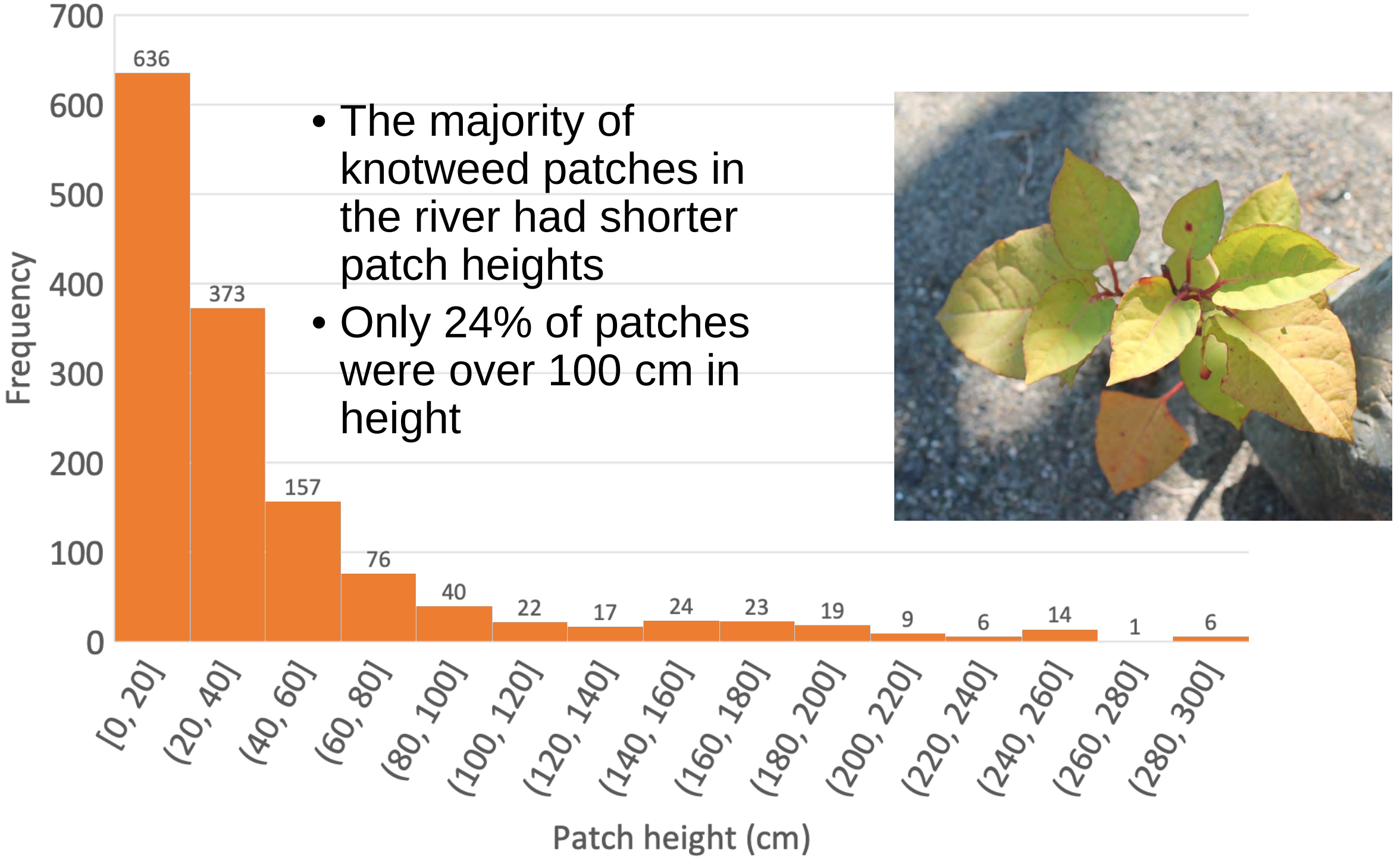


Chilliwack-Vedder River Survey in 2022 to gage the spread of knotweed in the 2021 flood due to two successive atmospheric rivers

Knotweed patches surveyed along the Chilliwack River

1690 patches in 2022 vs.
341 patches in 2019

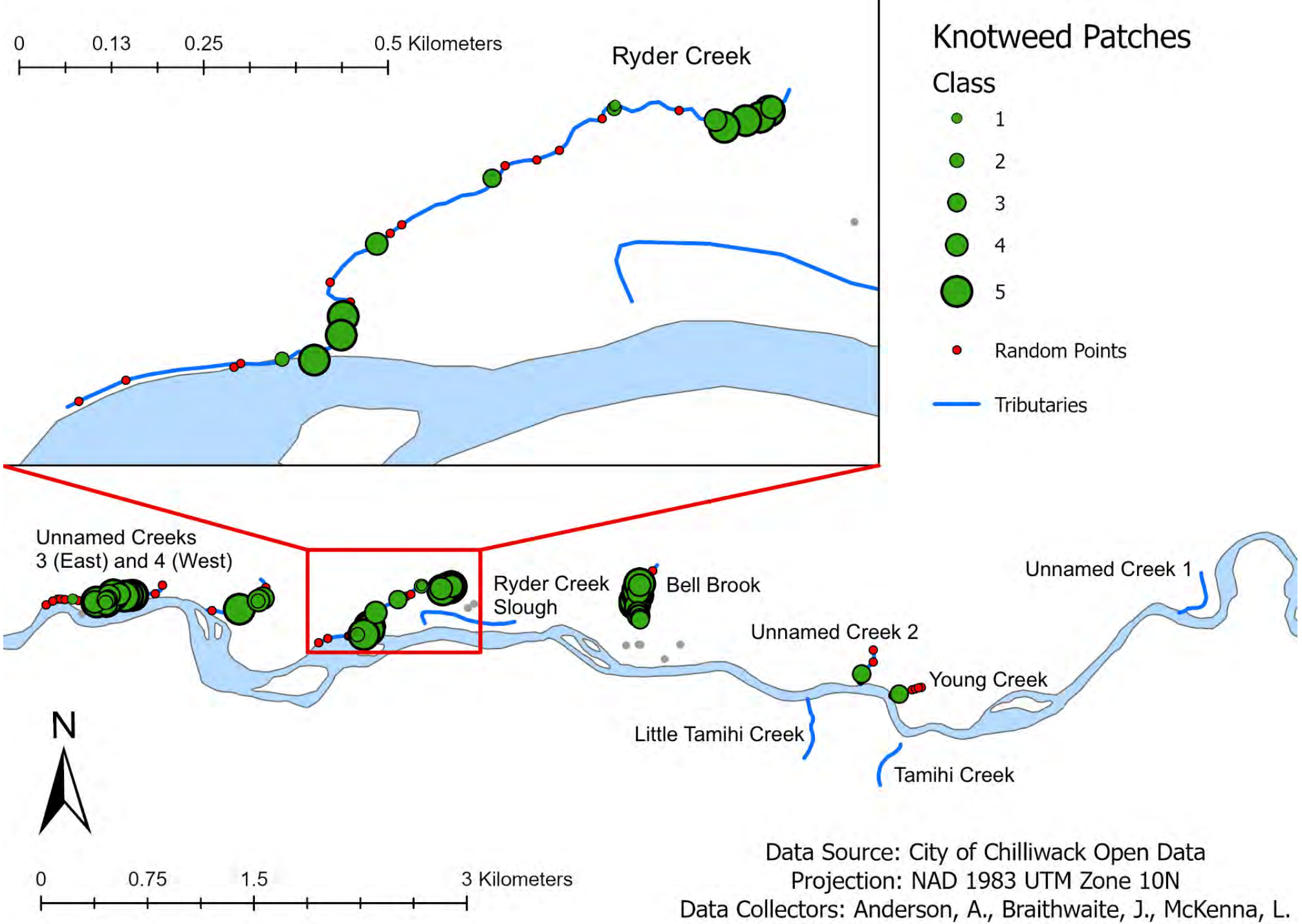




- The majority of knotweed patches in the river had shorter patch heights
- Only 24% of patches were over 100 cm in height

Chilliwack-Vedder River Tributary Survey in 2022

- 10 tributaries surveyed
- 6 had knotweed
- None of the S tributaries had knotweed
- Easternmost N tributary also did not have knotweed



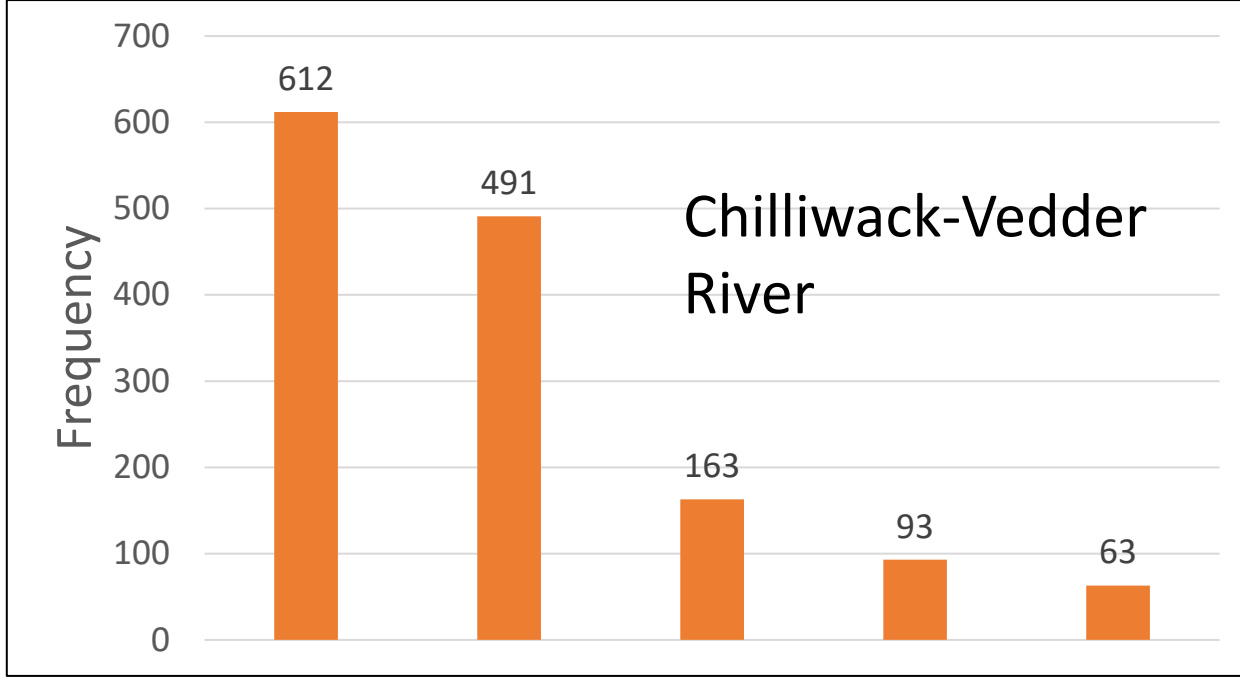
River vs. tributaries

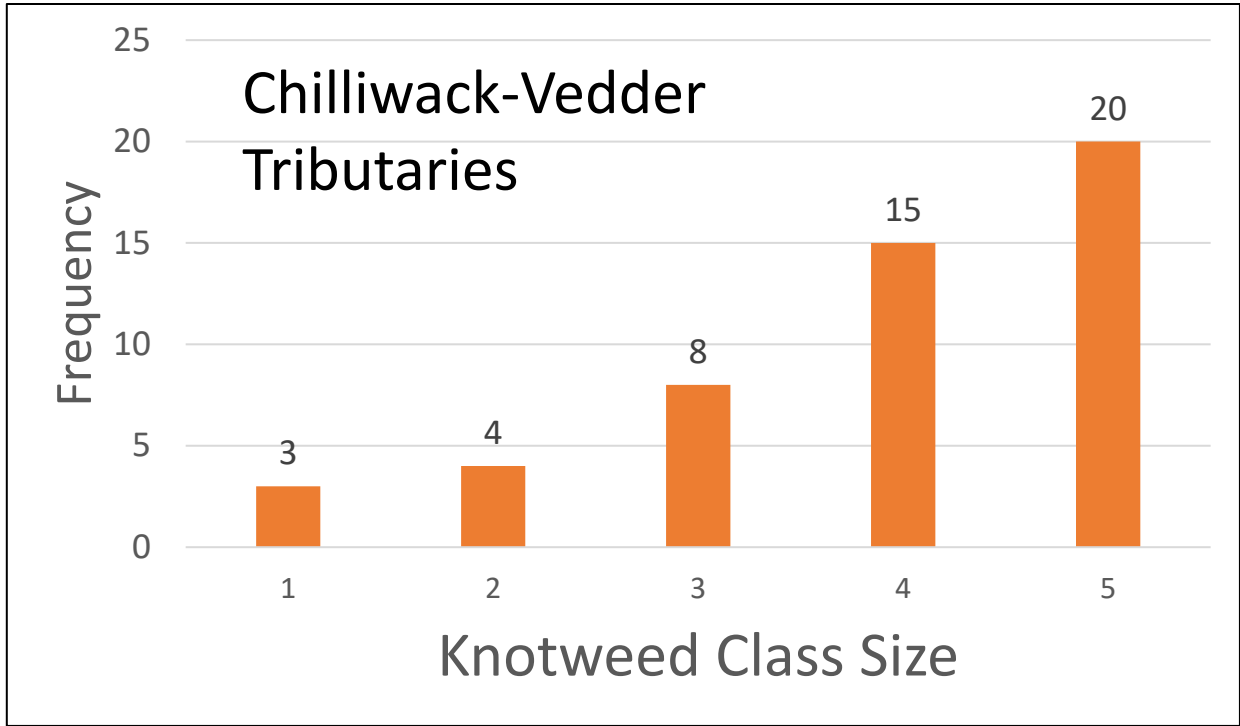
- Unlike the river, the majority of knotweed patches in the tributaries were large, well-established, and expansive
- A two-sample Kolmogorov-Smirnov test between the knotweed patches in the Chilliwack-Vedder River vs. the tributaries showed the distributions were significantly different

*****

Size classes:

(1) single shoot—less than 50cm,
(2) less than five shoots—less than 100cm,
(3) 5 – 10 shoots—greater than 100cm
(4) 10 – 20 shoots—greater than 200cm,
(5) more than 20 shoots—greater than 200cm.



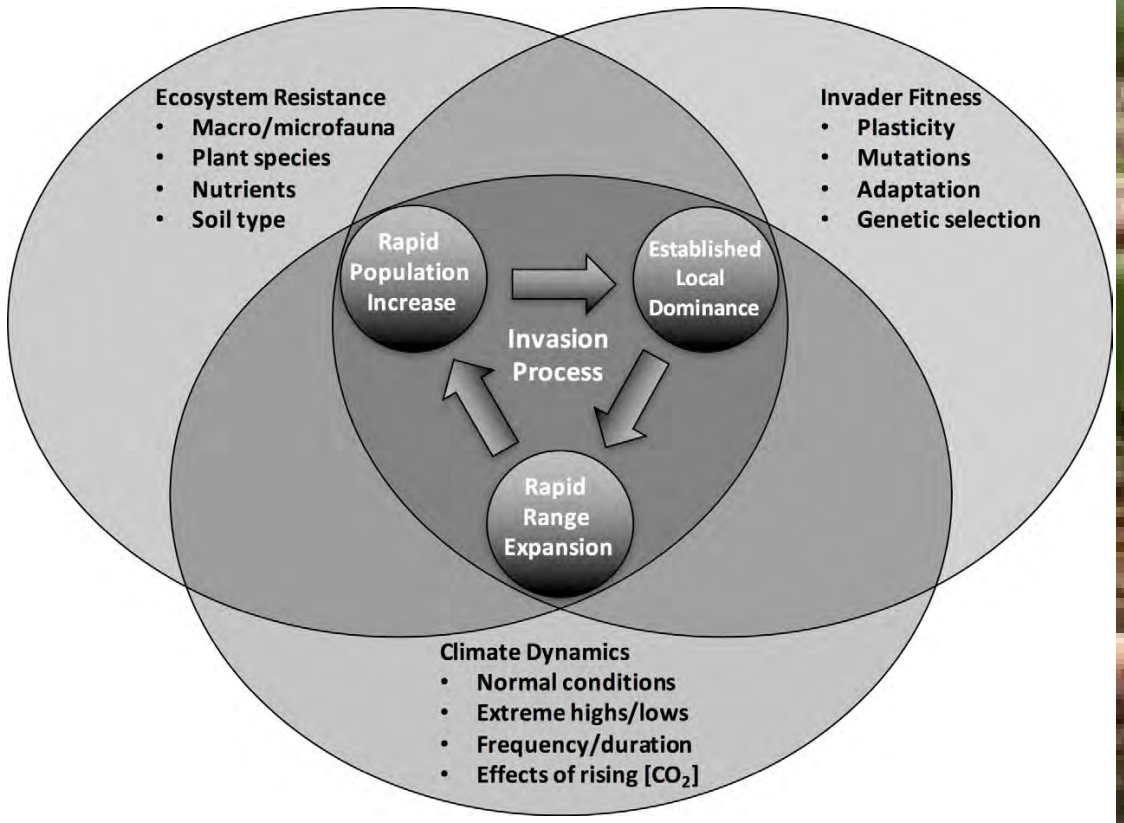


2023 update

- Most of the novel patches in 2022 persisted in 2023




Knotweed movement due to flooding highights importance of climate dynamics in the context of ecosystem resistance and invader fitness



Other invasive plants spread by flooding

Riparian species:

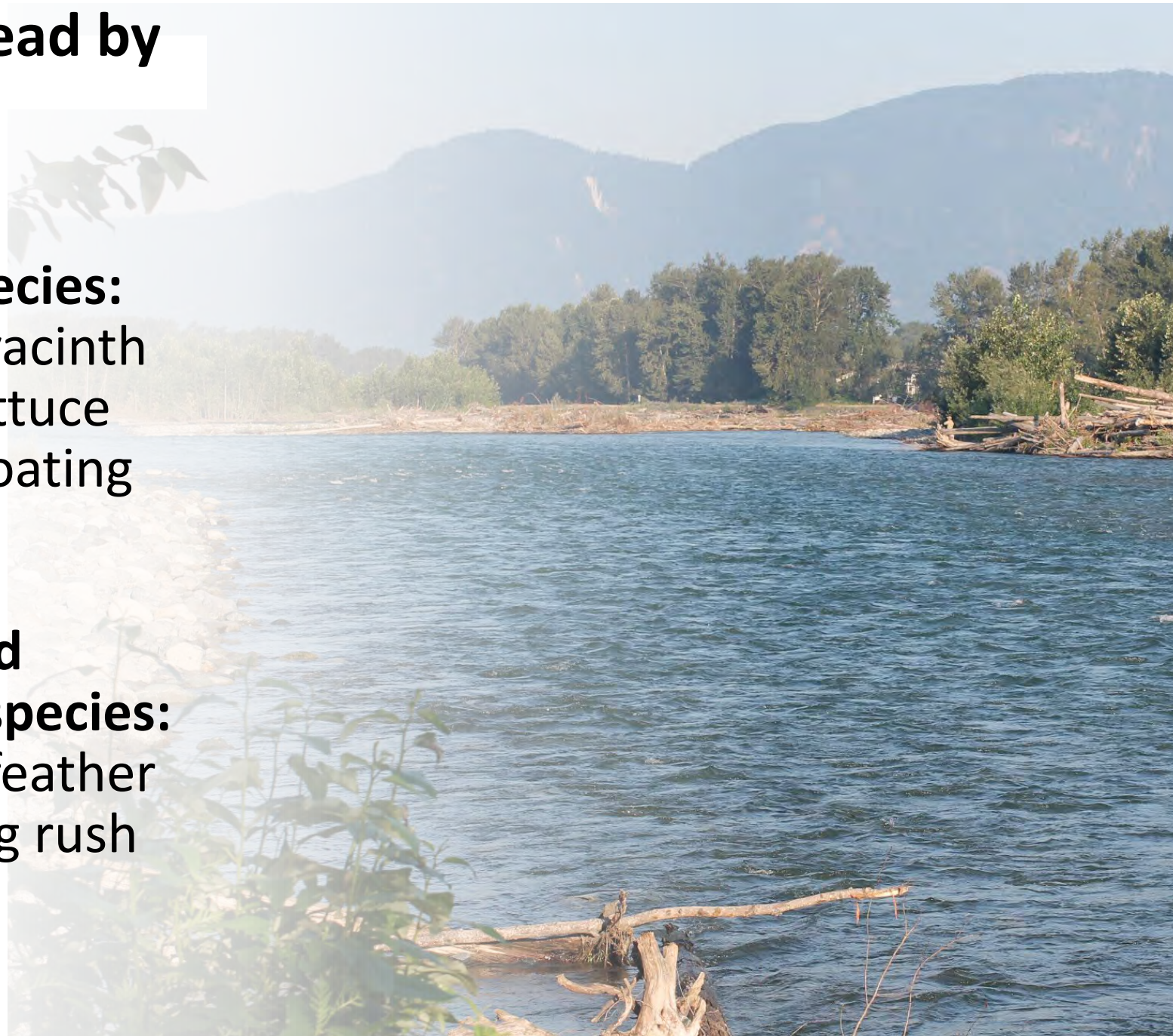
- Phragmites
- Giant reed
- Himalayan balsam
- Tamarix
- Buddleia

Aquatic species:

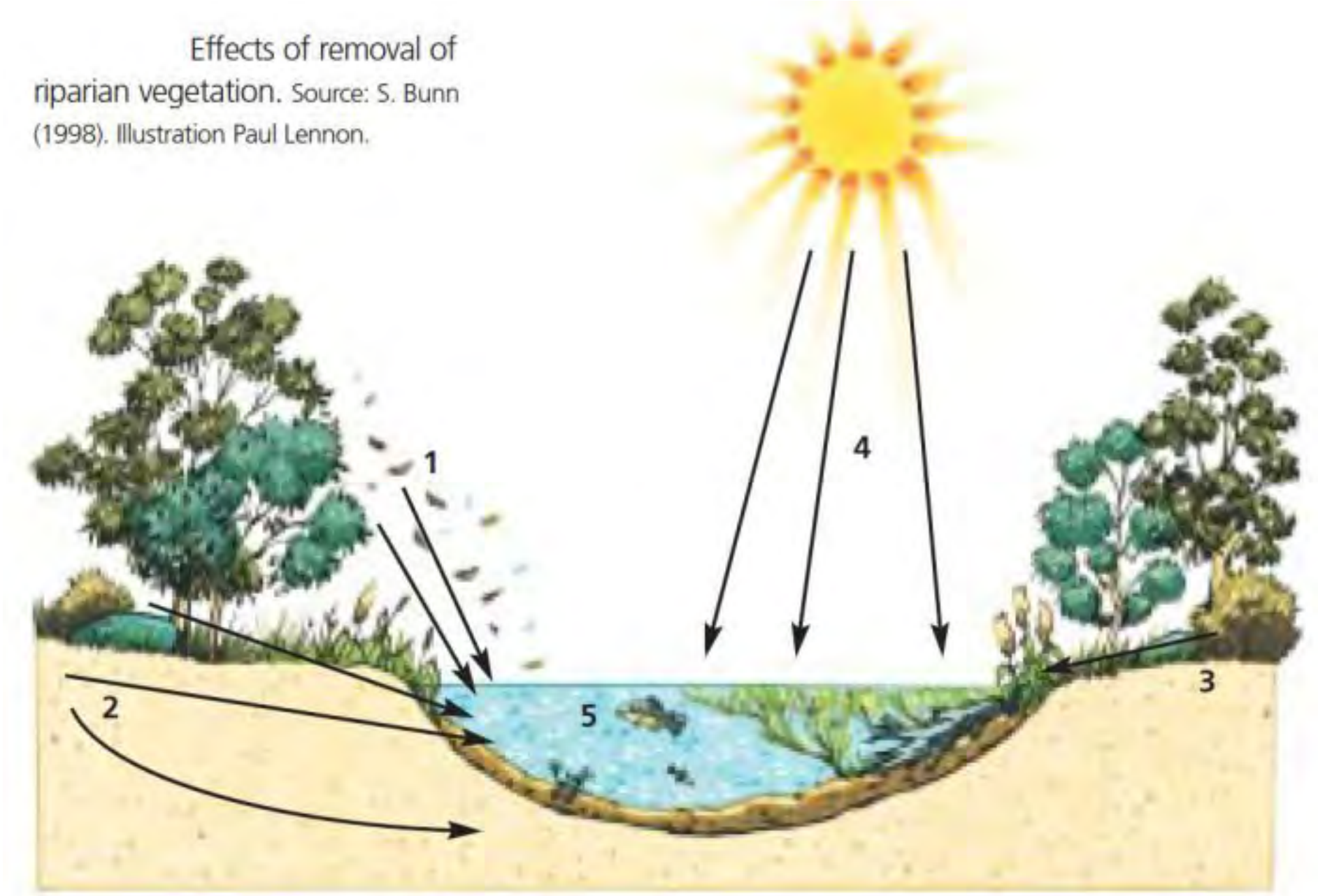
- Water hyacinth
- Water lettuce
- Yellow floating heart

Aquatic and emergent species:

- Parrot’s feather
- Flowering rush



Riparian Species



Effects of removal of riparian vegetation. Source: S. Bunn (1998). Illustration Paul Lennon.

https://www.friendsberowravalley.org.au/riparian-guidelines/

Photo by Susan Vincent

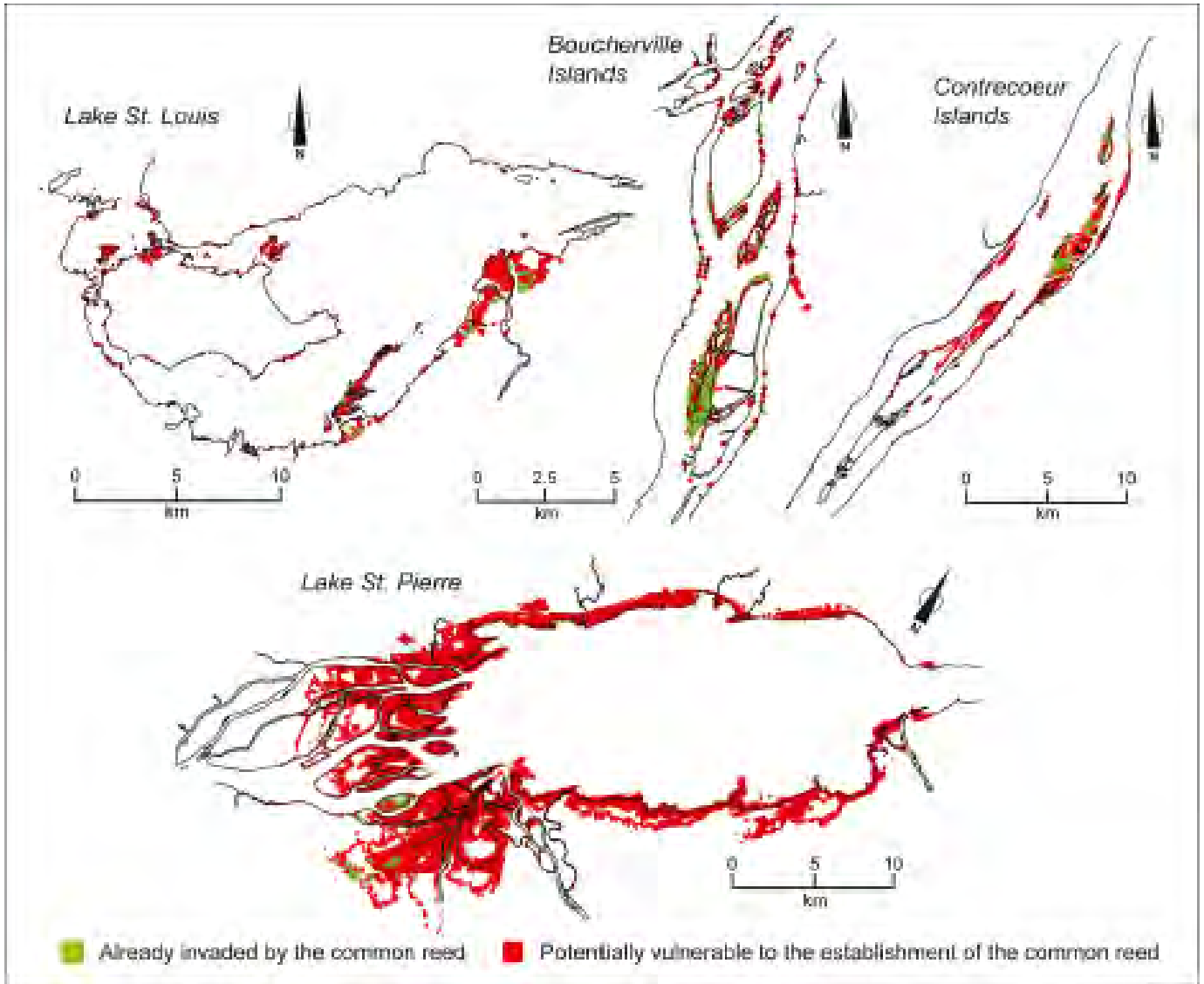
Phragmites (*Phragmites australis*)

- thrives with fluctuating water levels because it needs a temporary dry shoreline area to germinate (Tougas-Tellier et al. 2015, *Ecology and Evolution*)
- hurricane force winds resulted in bigger patches (Bhattarai and Cronin 2014, *PLoS ONE*)

Potential expansion of invasive Phragmites in Quebec with climate change


Claude Lavoie, Université Laval

- Many areas already amenable to Phragmites germination
- Climate model showed increased vulnerability by 21-50% by 2050
- Tougas-Tellier et al. 2015, *Ecology and Evolution*



E-Flora BC Distribution Map

Phragmites australis ssp. australis (common reed)

5.2 metre tall Phragmites stand.
Photo: J.M. Gilbert

Giant reed (*Arundo donax*)

- Recruitment through rhizome fragments, main shoots, or shoot pieces
- Aided by both flooding and use of bulldozers to manage giant reed (Boland 2008, *Madrono*; Goolsby et al. 2023, *Invasive Plant Sci. Manag*)

BOIP paper on Giant Reed

Goolsby JA, Moran PJ, Martinez Jiménez M, Chenghai Yang C, Canavan K, Paynter Q, Ota N, Kriticos DJ (2023). **Biology of invasive plants** 4. ***Arundo donax* L.** *Invasive Plant Science and Management*

Biology of Invasive Plants: a new series** within *Invasive Plant Science and Management*

Darren J. Kriticos[1,2], David R. Clements[3] and Antonio DiTommaso[4]

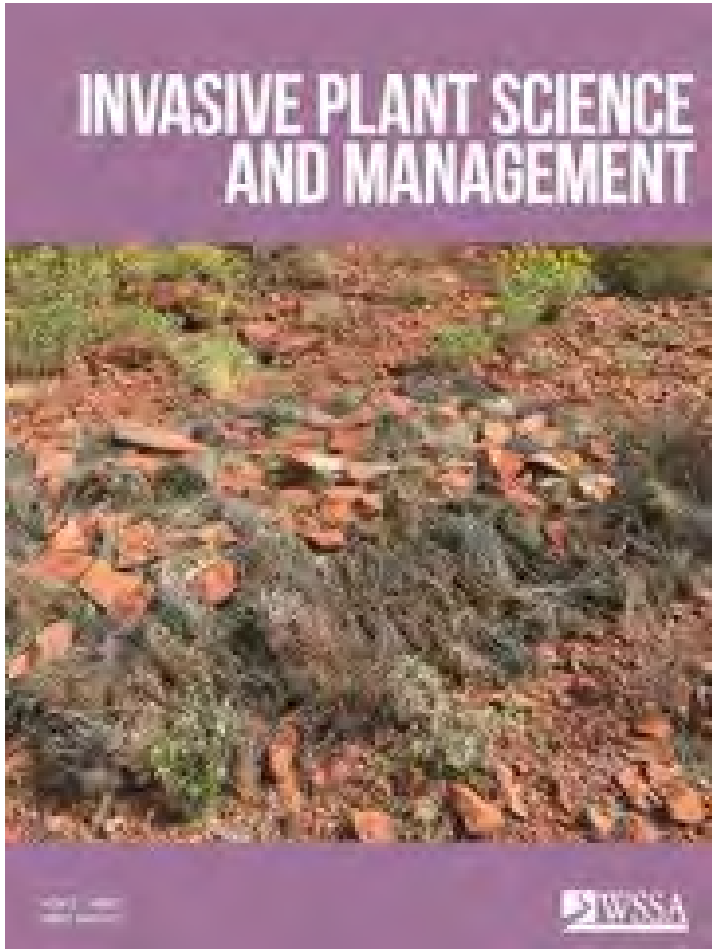
[1]CSIRO, Canberra, Australia; [2]School of Biological Sciences, University of Queensland, Brisbane, QLD, Australia; [3]Trinity Western University, Langley, BC, Canada and [4]Cornell University, Ithaca, NY, USA

Series Outline

These reviews are intended to collate published and unpublished information on the biology and ecology of emerging plant invasion problems globally. They will assemble background information to lay a foundation reference source concerning the biology and ecology of the focal species. Furthermore, they will provide vital practical recommendations, highlighting invasion risks and their management.

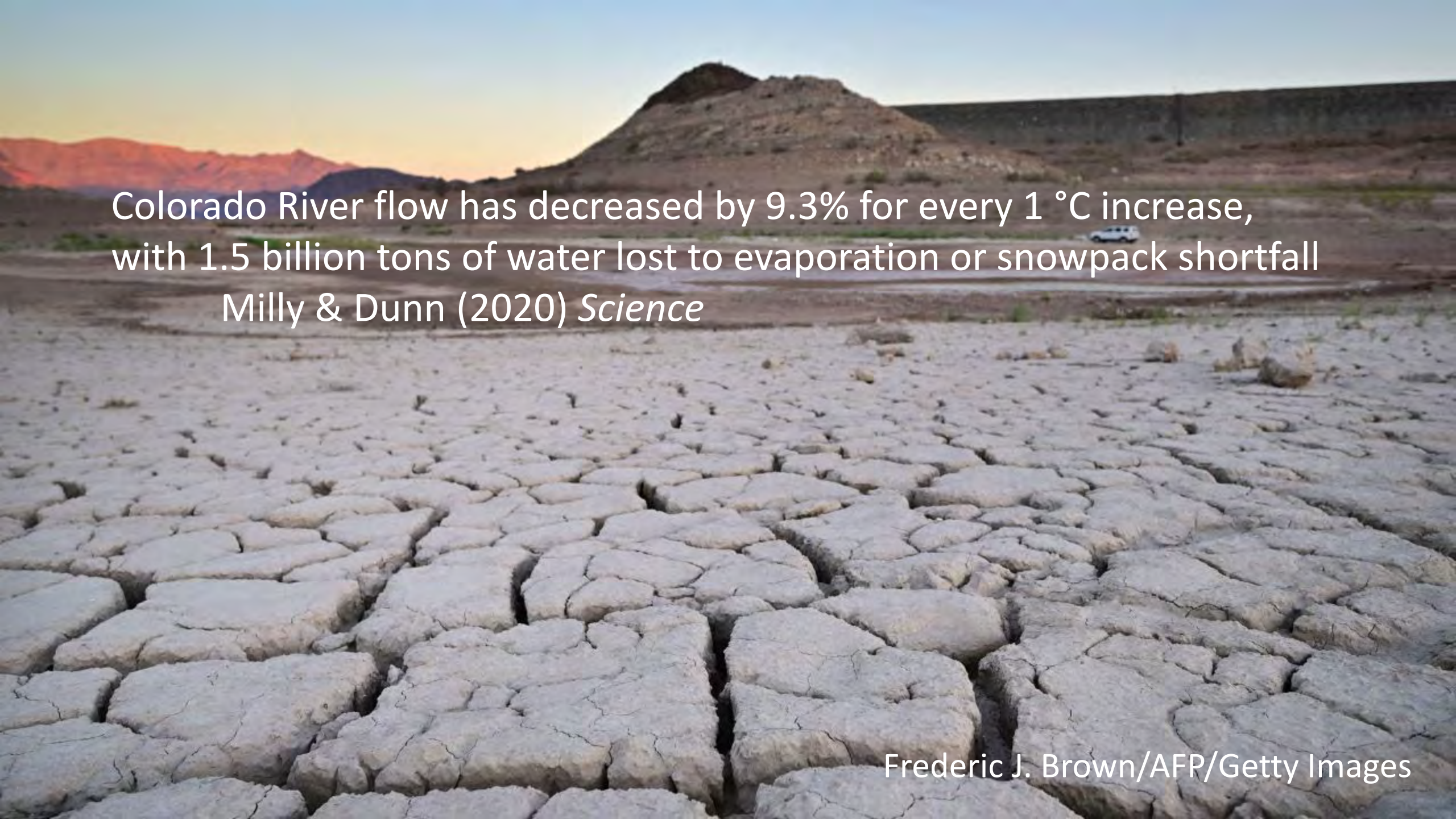
This series builds on foundations laid in more regional series such as the Biology of Australian Weeds (Groves and Panetta 2014), Biology of Canadian Weeds (Cavers and Mulligan 1972), and Biology of Invasive Alien Plants in Canada (Warwick et al. 2003), and retains many of the features of these review series. The Biology of Invasive Plants series addresses the fact that biological invasions are a global problem. We want to provide a platform for identifying global risk patterns to alert biosecurity agencies and weed managers of emerging threats and to provide a consolidated resource to help manage these emerging threats.

**as of 2020



Unhealthy river circulation?

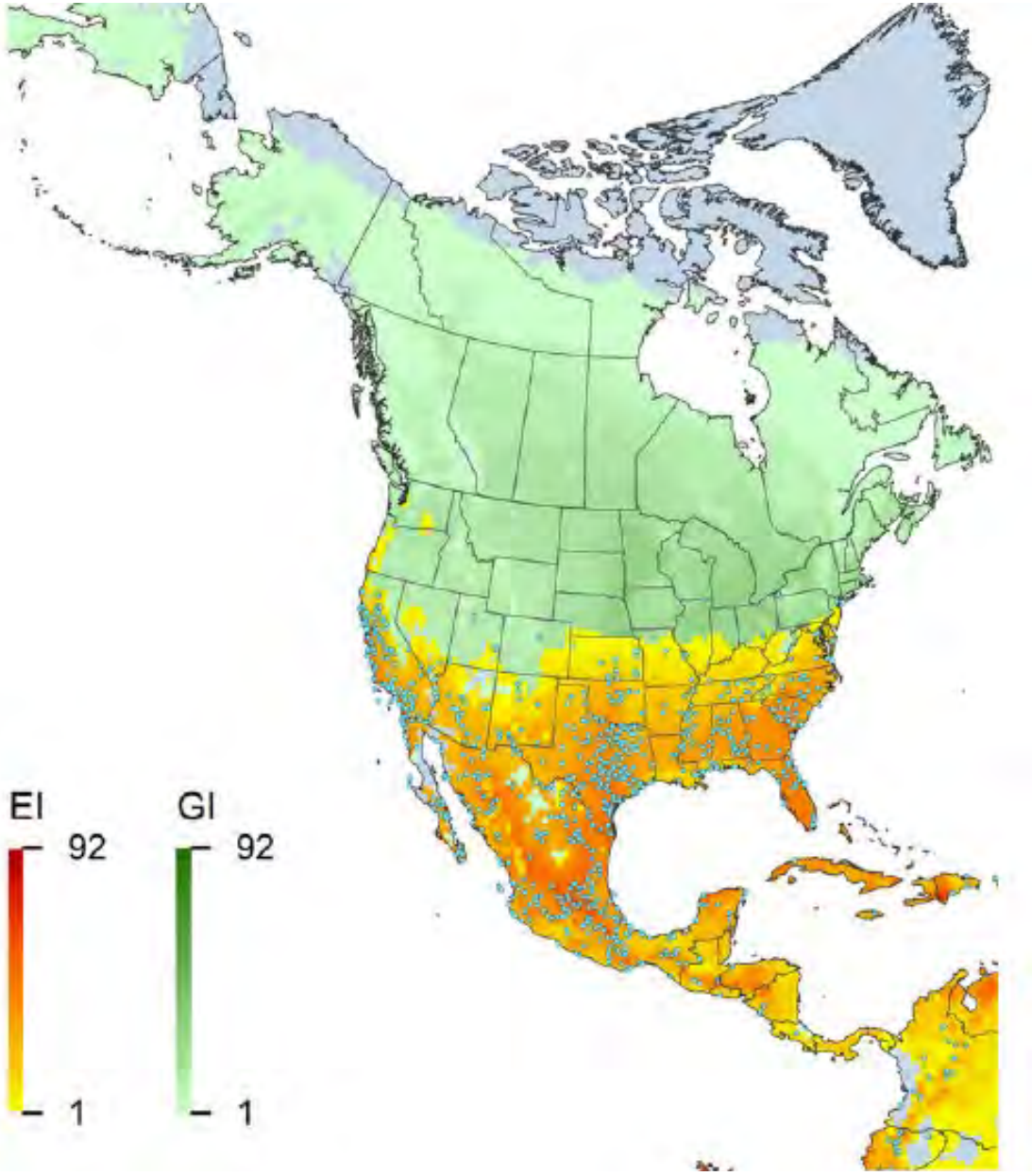
By User:Kmusser modified by User:Aymatth2 to show dam locations – File:Riogranderivermap.png, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=21959793


Colorado River flow has decreased by 9.3% for every 1 °C increase,
with 1.5 billion tons of water lost to evaporation or snowpack shortfall
Milly & Dunn (2020) *Science*
Frederic J. Brown/AFP/Getty Images

Giant reed and climate change

- “Invasions have been facilitated by human-aided dispersal of plants and favored by human alteration of riparian ecosystems, especially the damming of rivers”
- “clearing of forests and manipulation of water flow are likely to increase invasion risk”

Goolsby et al. (2023)



Himalayan balsam (*Impatiens glandulifera*)

- seeds released ballistically, adapted for water dispersal
- effective colonizer of disturbed riverbanks (Čuda et al. 2017, *Divers Distrib*)

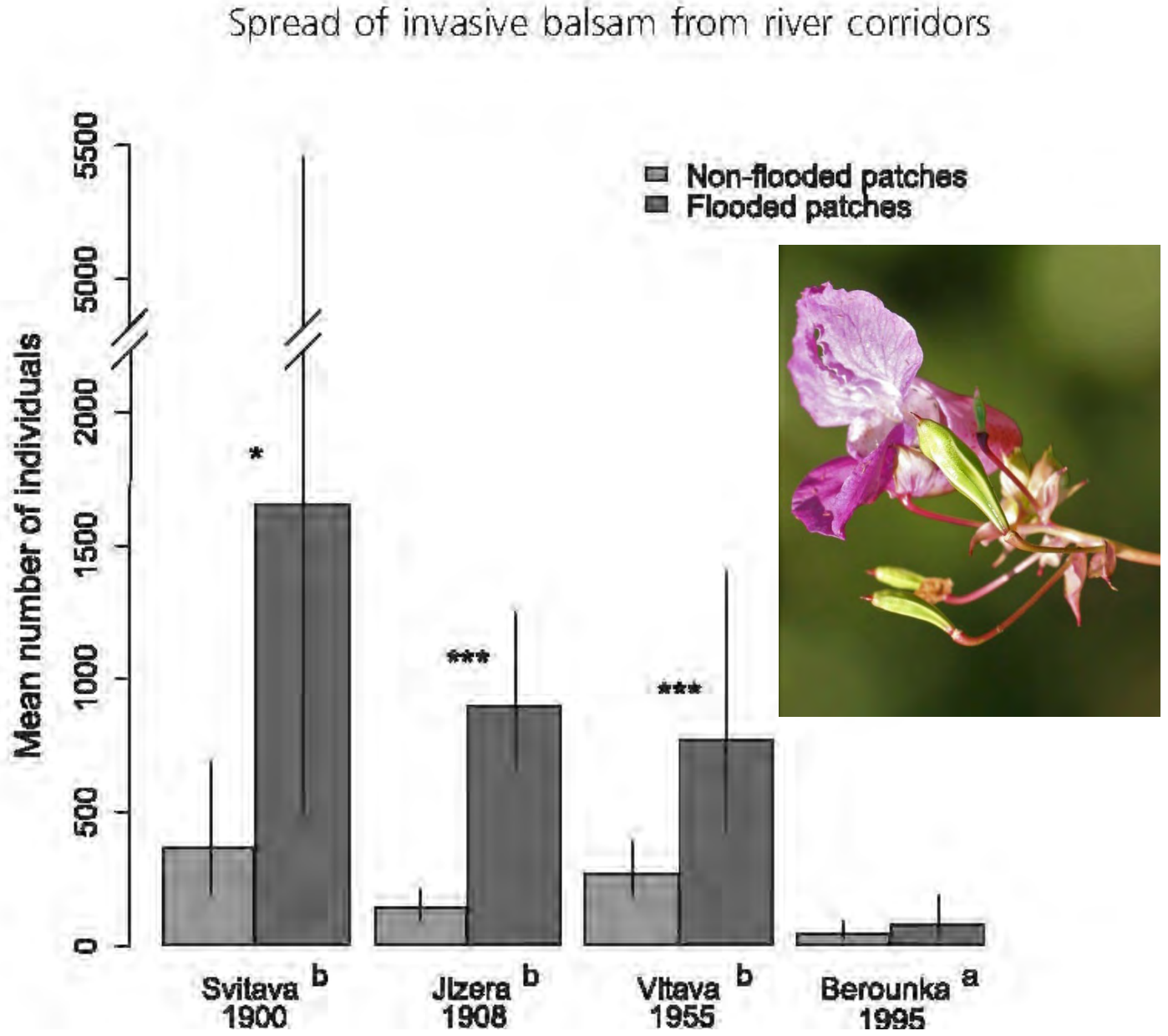



Photo by Paul A Graham

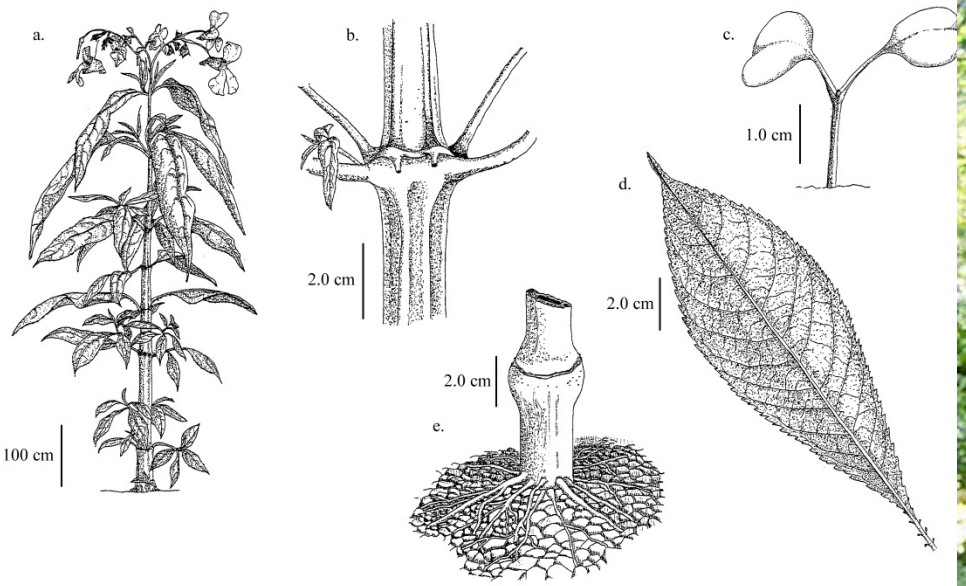


Figure 1. Vegetative characteristics of *Impatiens balsamifera*. a) Habit of plant. b) Stem/branch node showing finger-like glandular stipules. c) Seedling at cotyledon stage. d) Foliage leaf. e) Base of stem showing swollen first node and adventitious roots on the soil surface. Illustrated by R. Staniforth

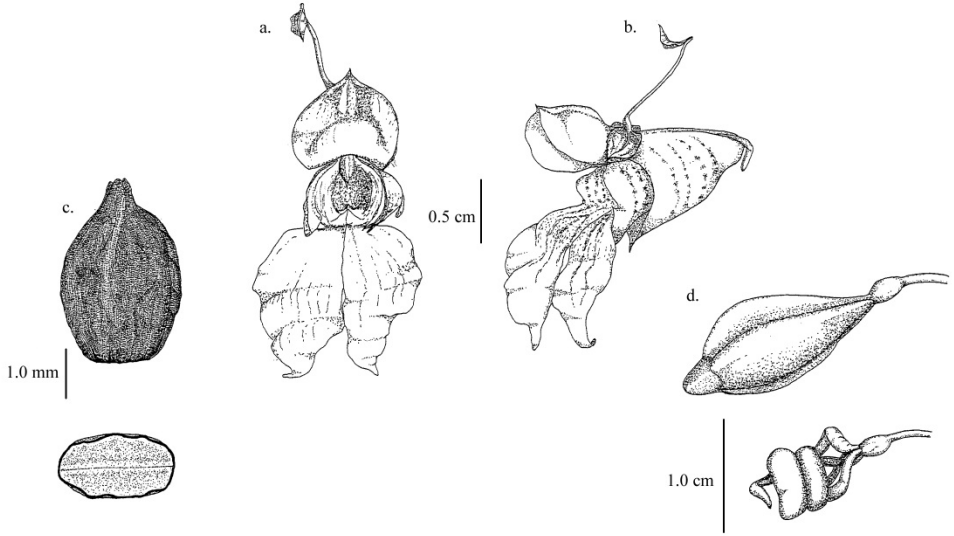
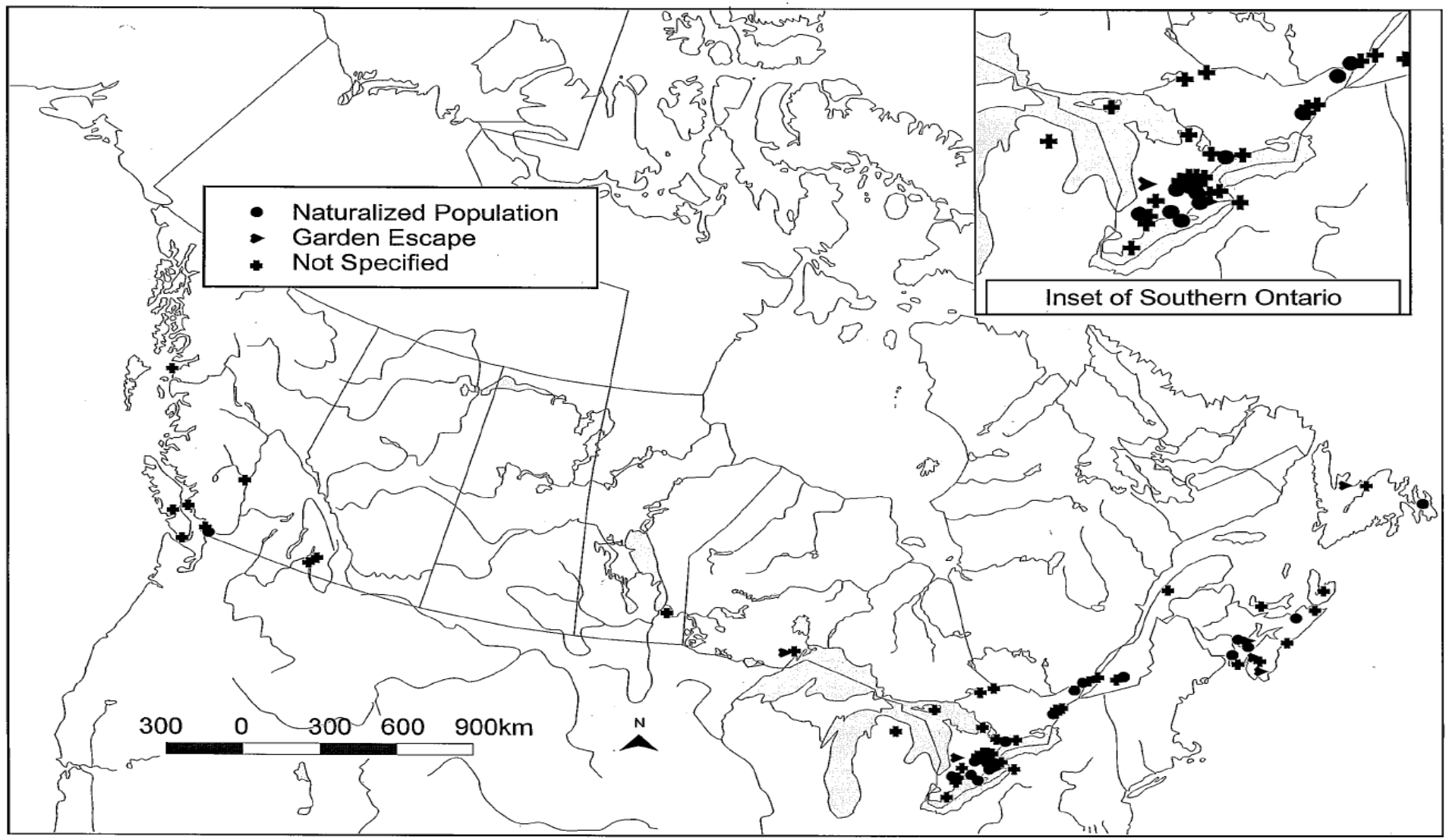


Figure 2. Reproductive characteristics of *Impatiens balsamifera*. a) Flower, anterior view. b) Flower, side view. c) Seed, side view (upper) and cross-section (lower). d) Capsule, side view of intact capsule (upper), side view of dehisced capsule (lower). Illustrated by R. Staniforth

Clements et al. (2008) *Can J Plant Sci*


Photo by Paul A Graham



- Is the range of Himalayan balsam in Canada still expanding?
- Clements et al. (2008) *Can J Plant Sci*

E-Flora BC Distribution Map

impatiens glandulifera (policeman's helmet)

Gulf of Alaska

British Columbia

Alberta

Queen Charlotte Sound

Edmonton

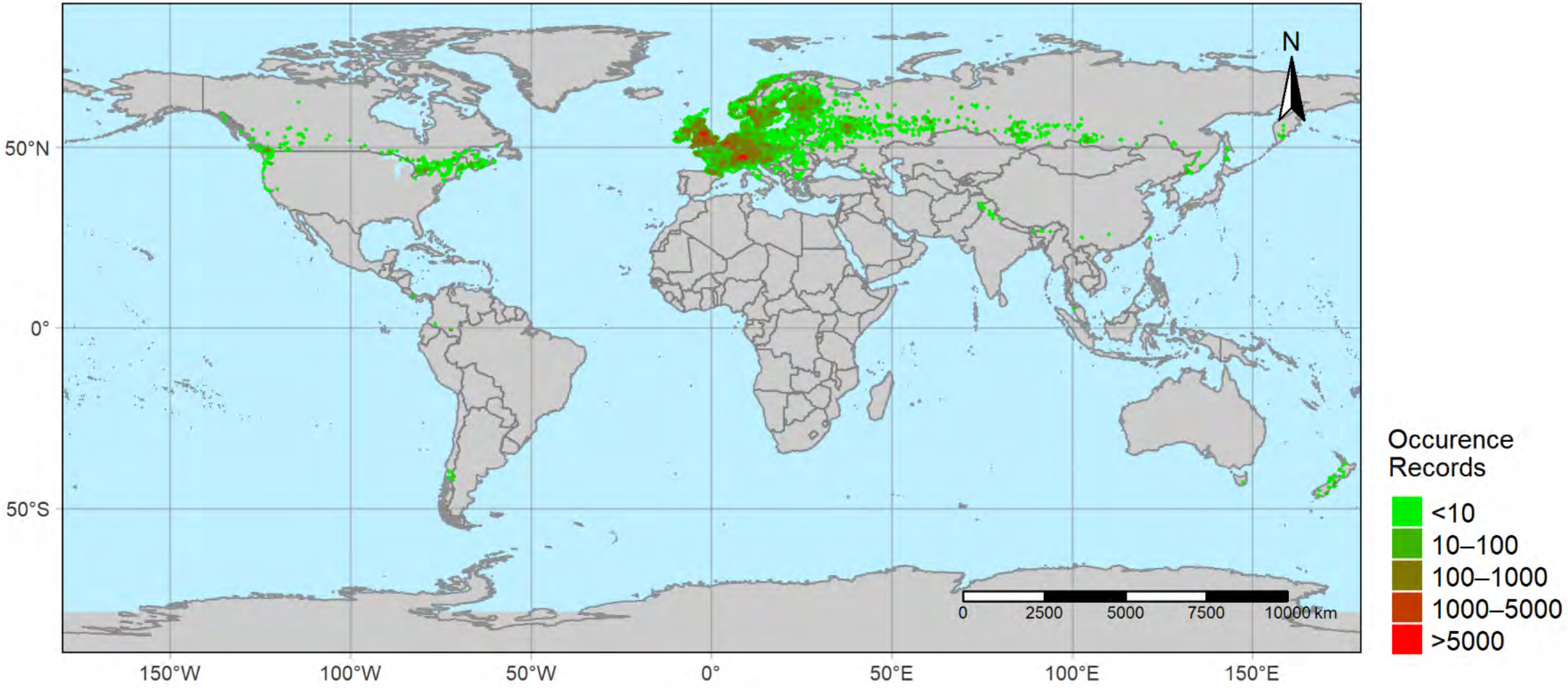
Calgary

Vancouver

Seattle

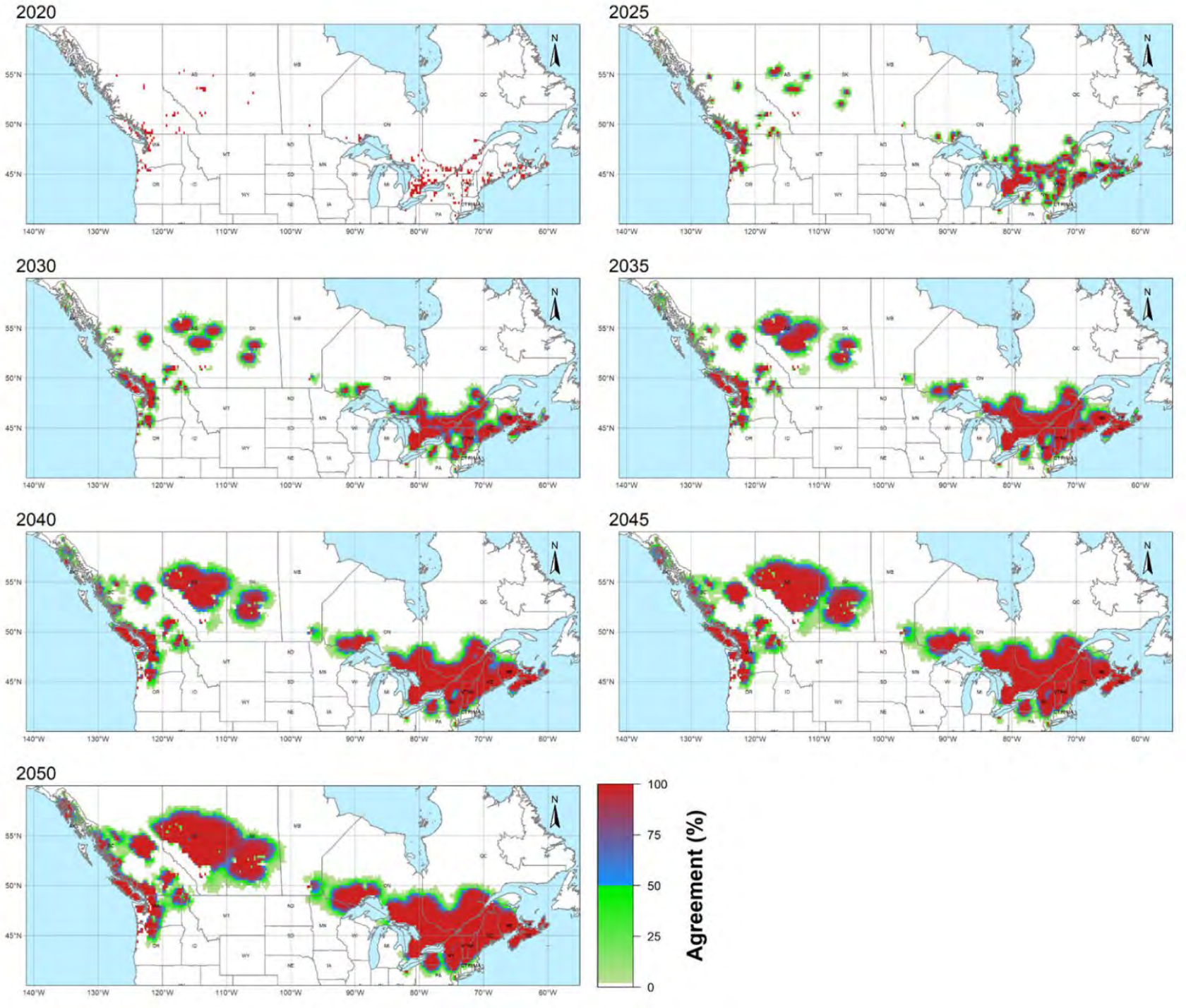
300 km

300 mi



Current world range of Himalayan Balsam
Kanmaz et al. (2023) *Plants*

5-year inter-simulation agreement maps for the projected invasive range of *Impatiens glandulifera* in North America using MaxEnt under the RCP 4.5 climate change scenario (Kanmaz et al. 2023 *Plants*)



Tamarisk in bloom at Grapevine, Arizona. Flickr photo by cogdogblog.

Tamarix (*Tamarix ramosissima*)

- recruitment through rhizome fragments
- tamarix may become acclimated to flooding
- photosynthesis rates returned to normal after three weeks of flooded conditions (Polacik and Maricle 2013, *Environ Exp Bot*)

E-Flora BC Distribution Map

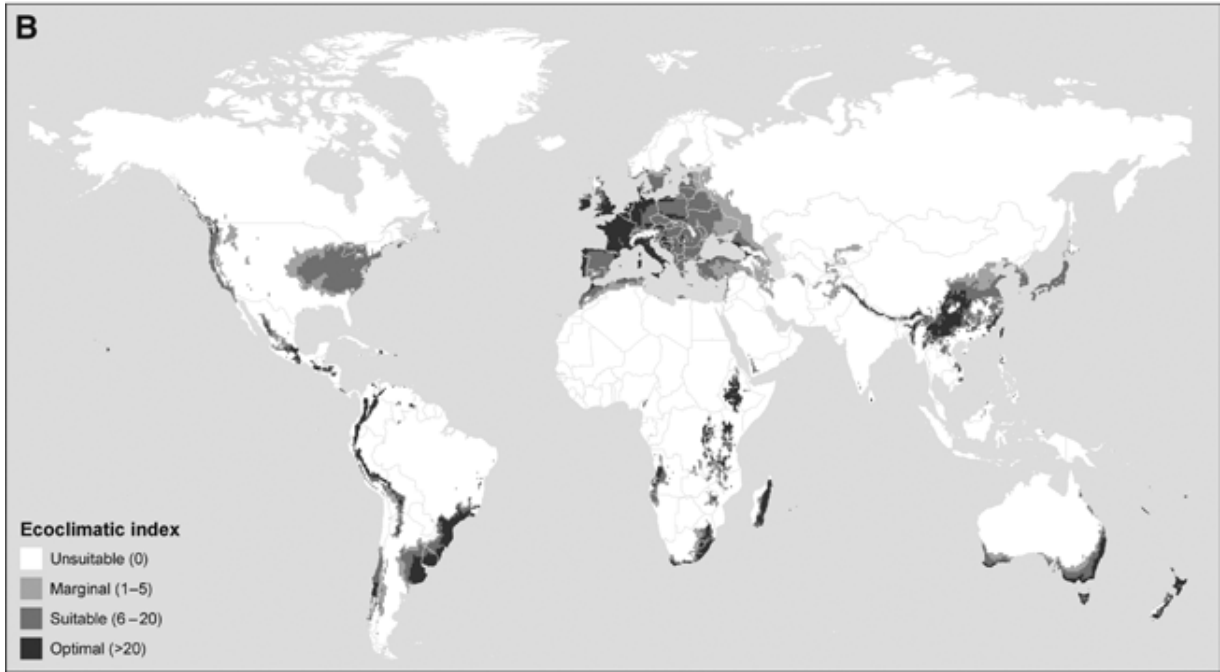
Tamarix ramosissima (saltcedar)

Photo by R. Mueller

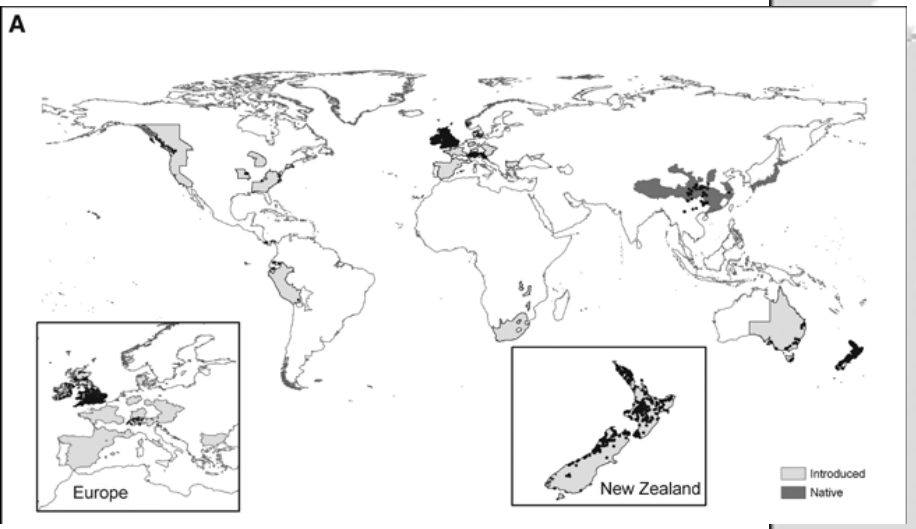
Buddleia (*Buddleia davidii*)

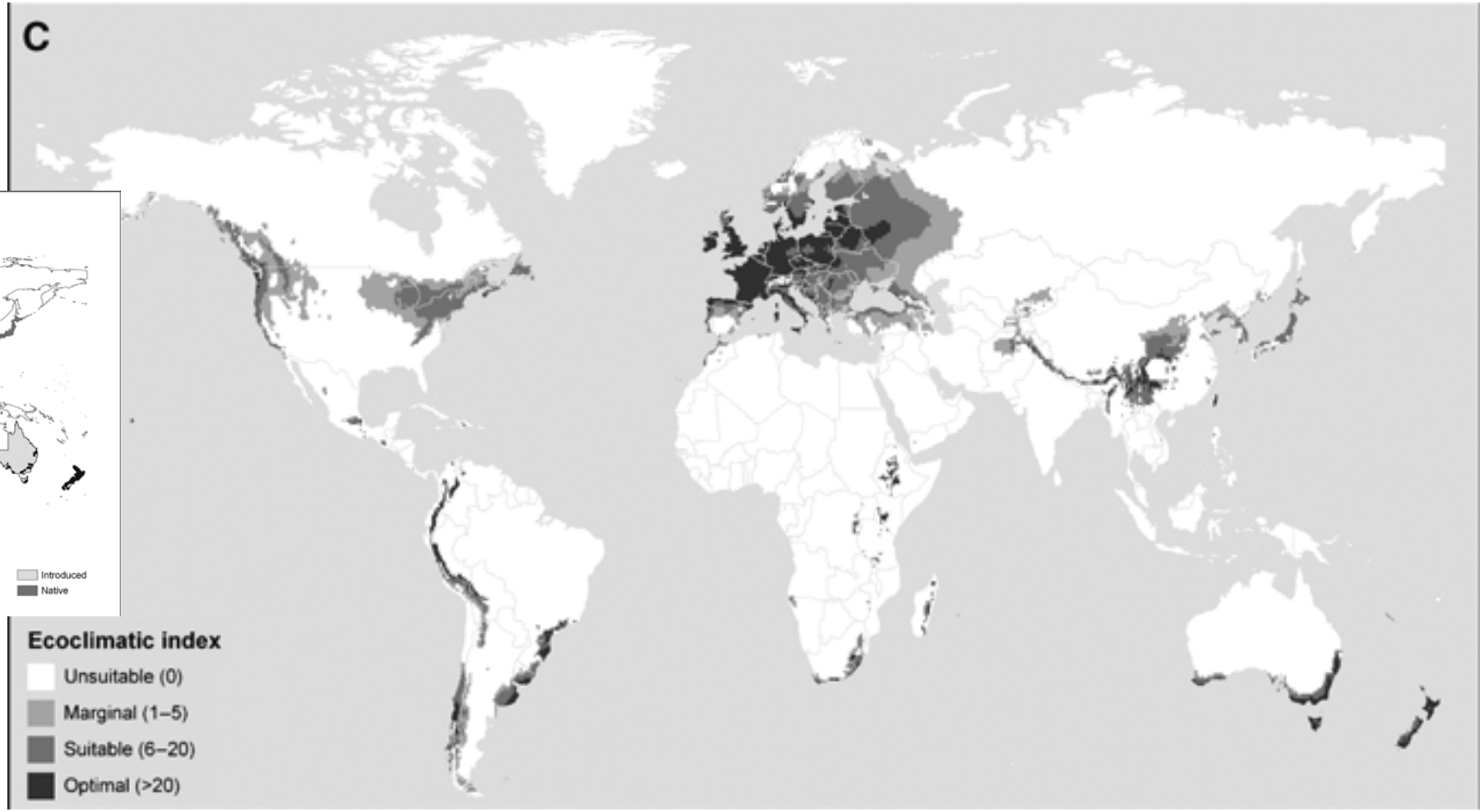
- Buddleia (butterfly bush) is tolerant of flooding and thrives in riparian zones
- Perennial shrub that produces numerous seeds (40,000 per inflorescence) with dormancy and can also regenerate vegetatively from stem and root fragments

Buddleia: current distribution (A) and suitability (B) according to CLIMEX modelling (Kriticos et al. 2011, *Weed Research*)

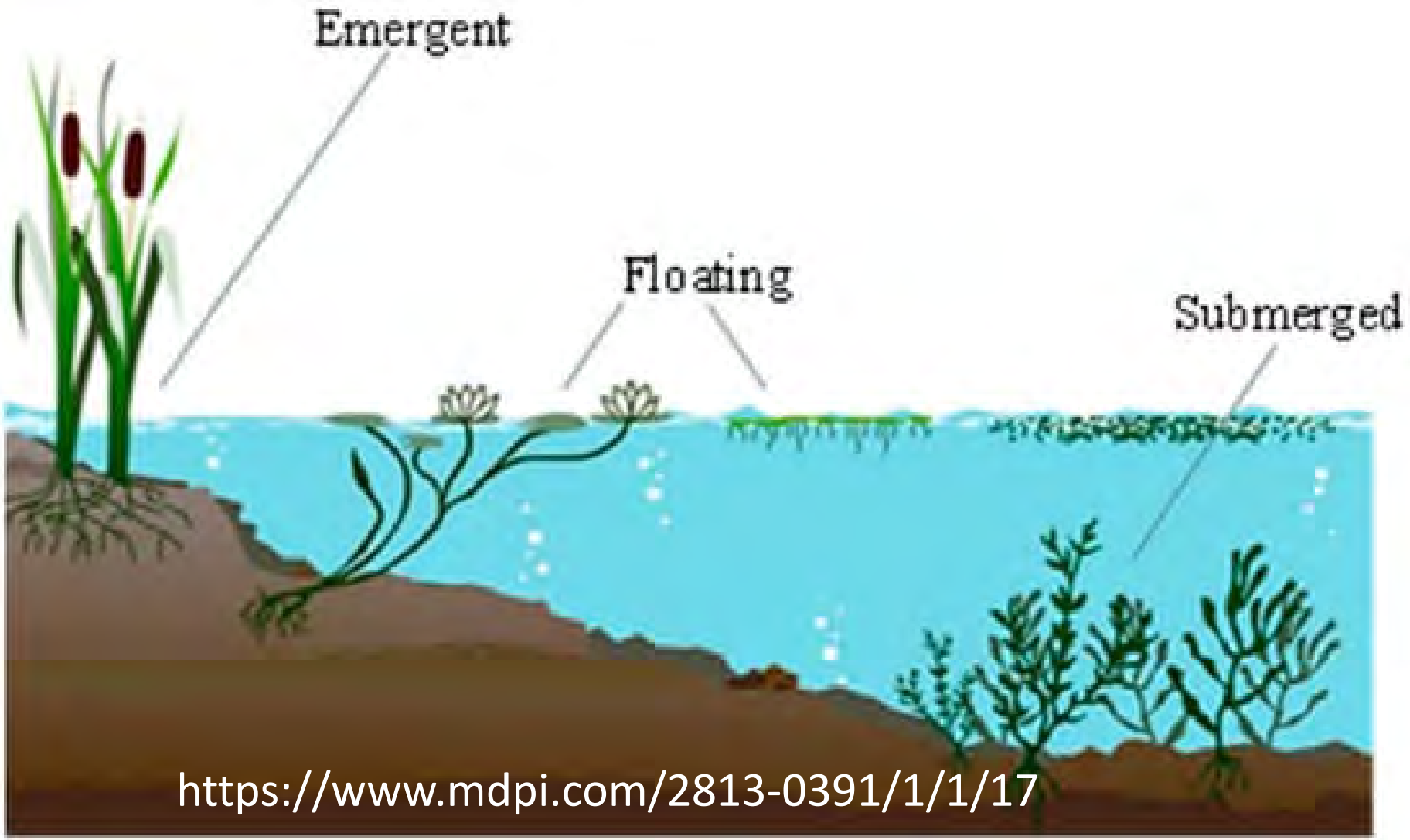


Buddleia: Current (A) vs. future distribution (B) via CLIMEX modelling and 2080 MIROC-H projections (Kriticos et al. 2011, *Weed Research*)





Aquatic species



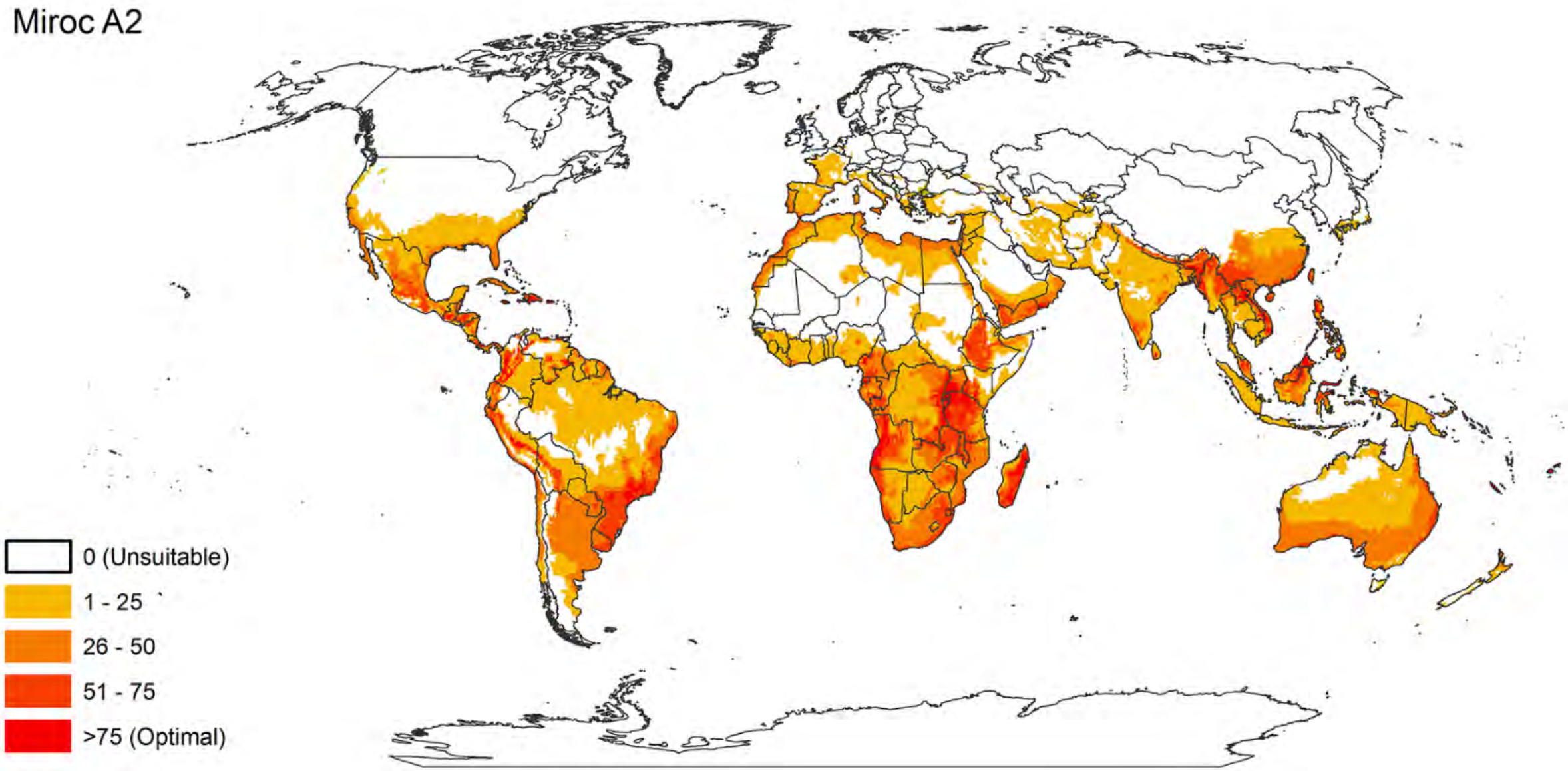
https://www.mdpi.com/2813-0391/1/1/17

Water hyacinth

Pontederia crassipes

- tropical aquatic plant from Brazil
- has spread to nearly all tropical and subtropical regions globally
- also introduced to higher latitudes but limited by freezing winter temperatures

Photos by Anil Shrestha in Nepal



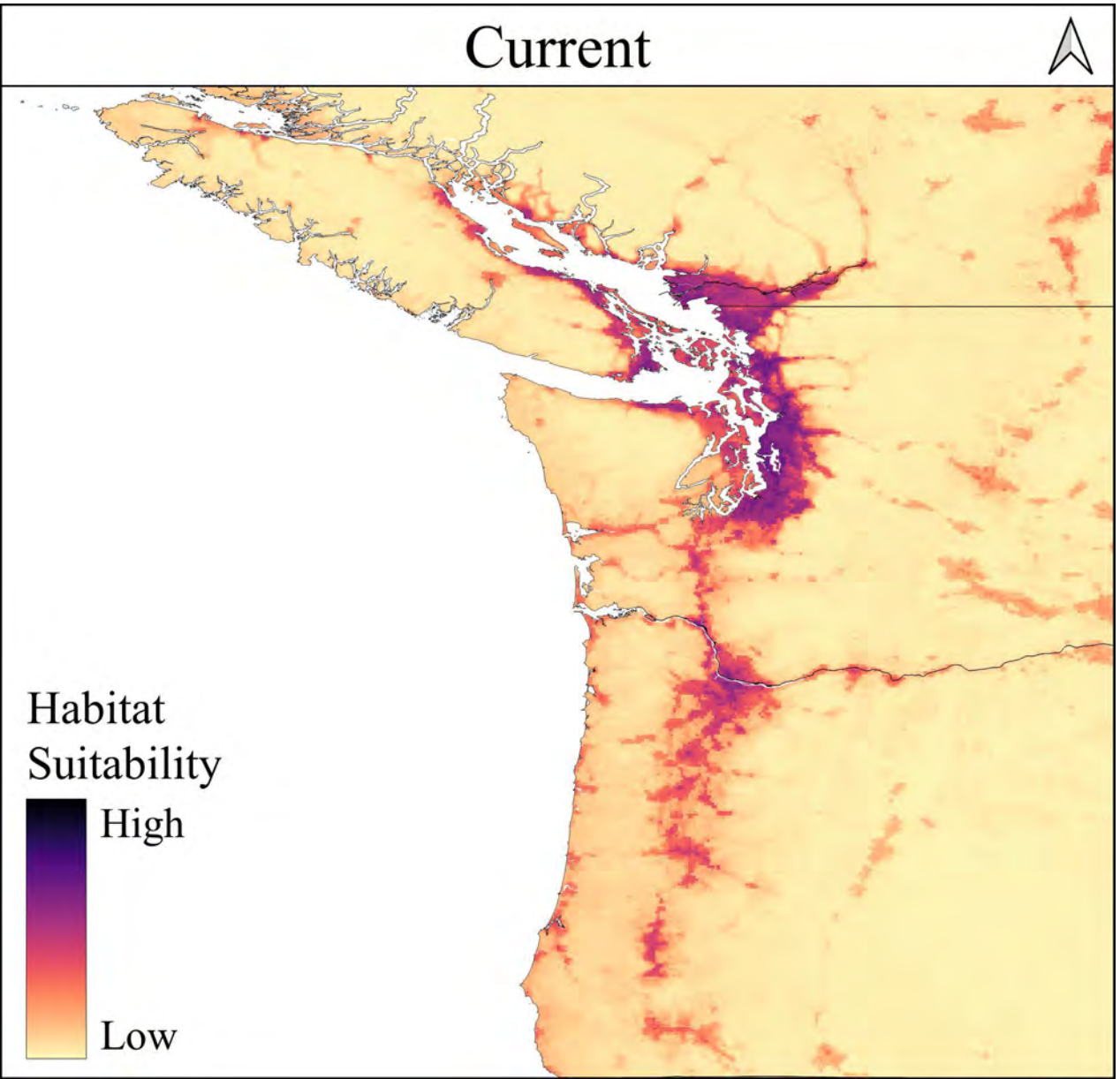
Climate suitability for water hyacinth under a 2080 climate scenario, Miroc A2 (Kriticos & Brunei 2016, *PLoS ONE*)

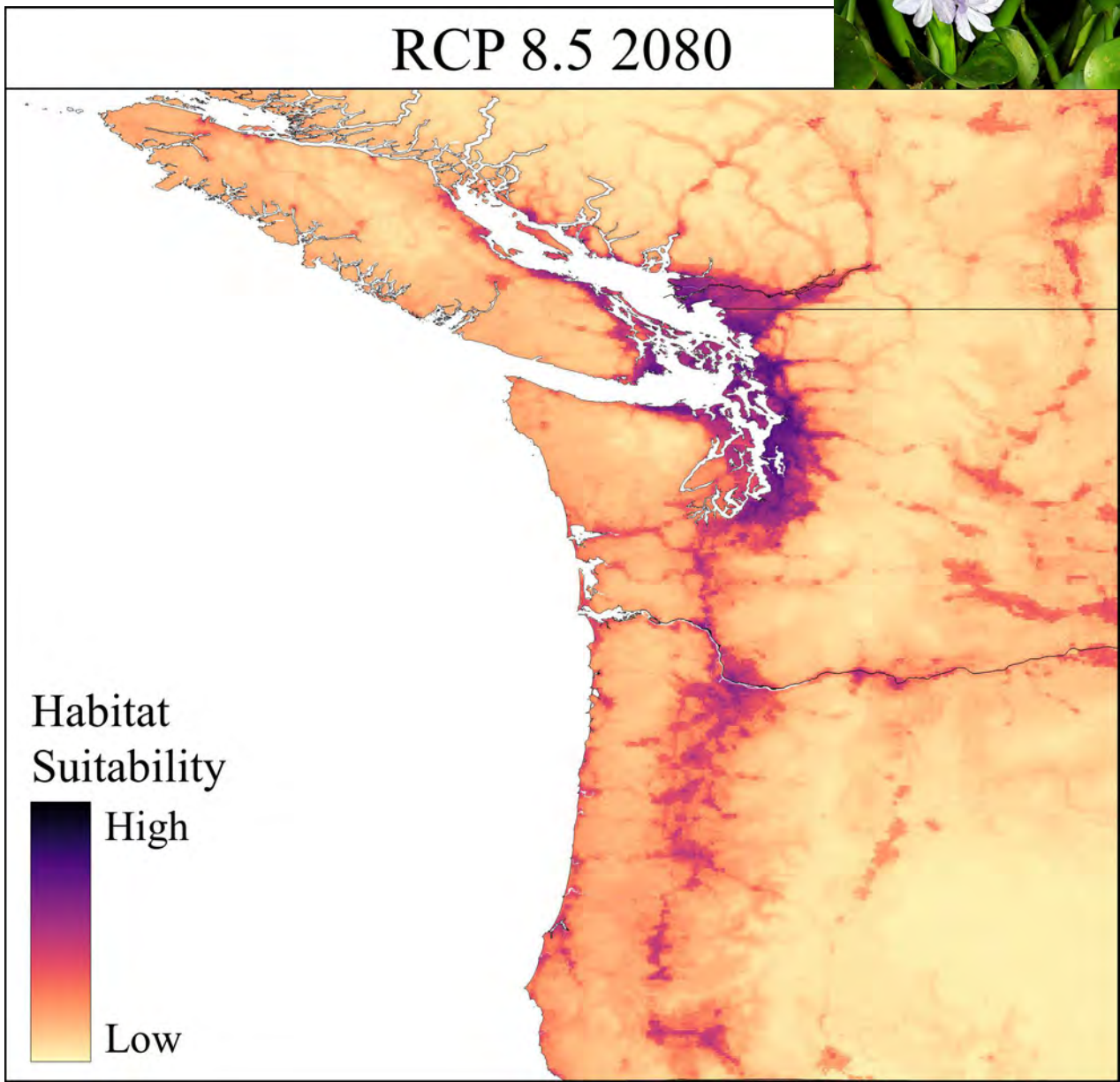
Pond in Surrey, BC where water hyacinth overwintered in 2020 but not 2021
(L-R: Delia Anderson, Emma Nikkel, Tasha Murray)

Water hyacinth in the Pacific Northwest: methods

- collected species occurrence data for North America (GBIF, EDDmapS, IAPP) and processed these records
- correlative ensemble modelling approach utilizing 6 different algorithms
- climate change scenarios via general circulation models (GCMs)

Water hyacinth habitat suitability in the Pacific Northwest according to our ensemble modelling





Water hyacinth infestation in Malaysia

Photo by Zufarzaana Zulkeflee

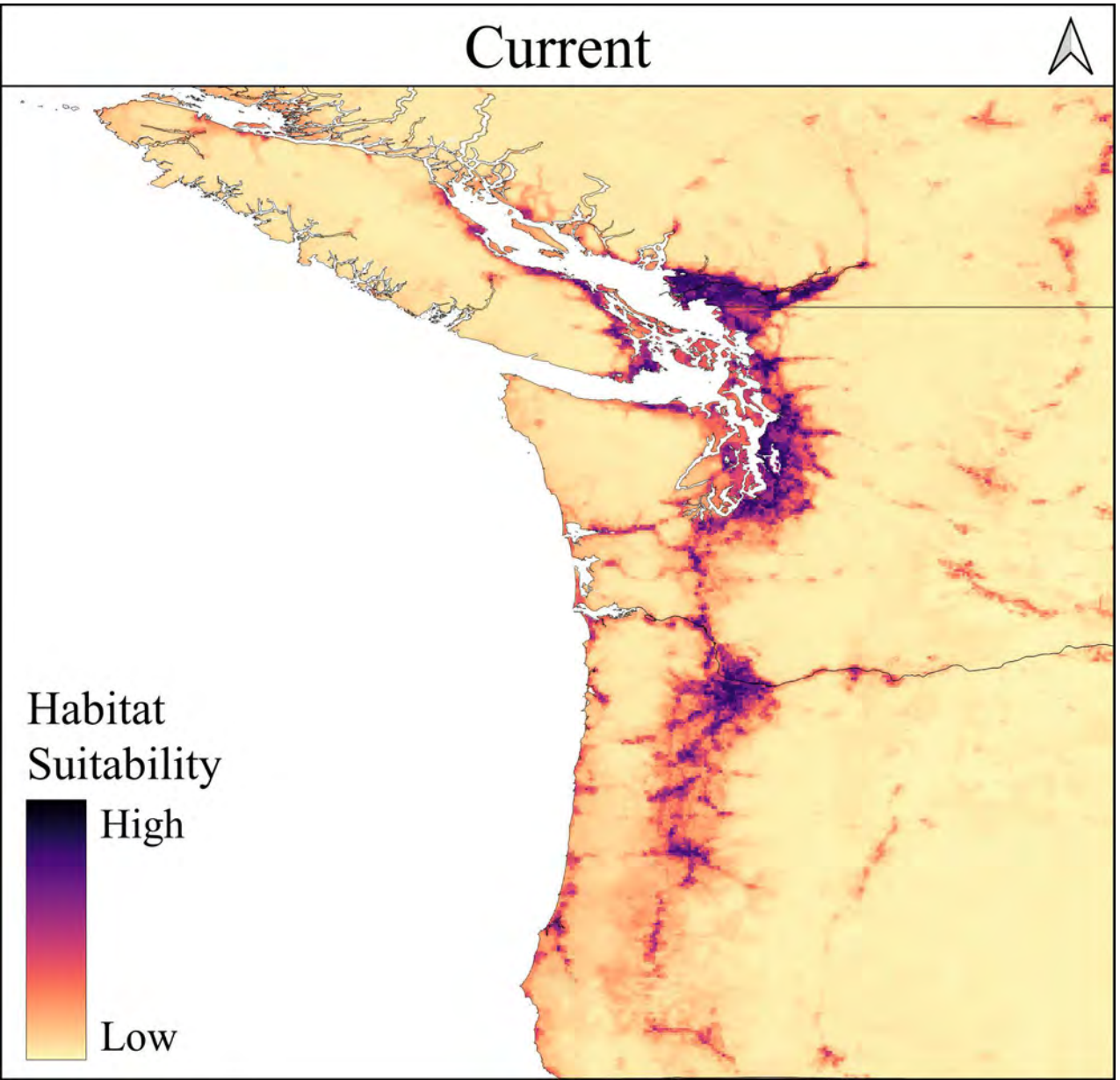
Water lettuce

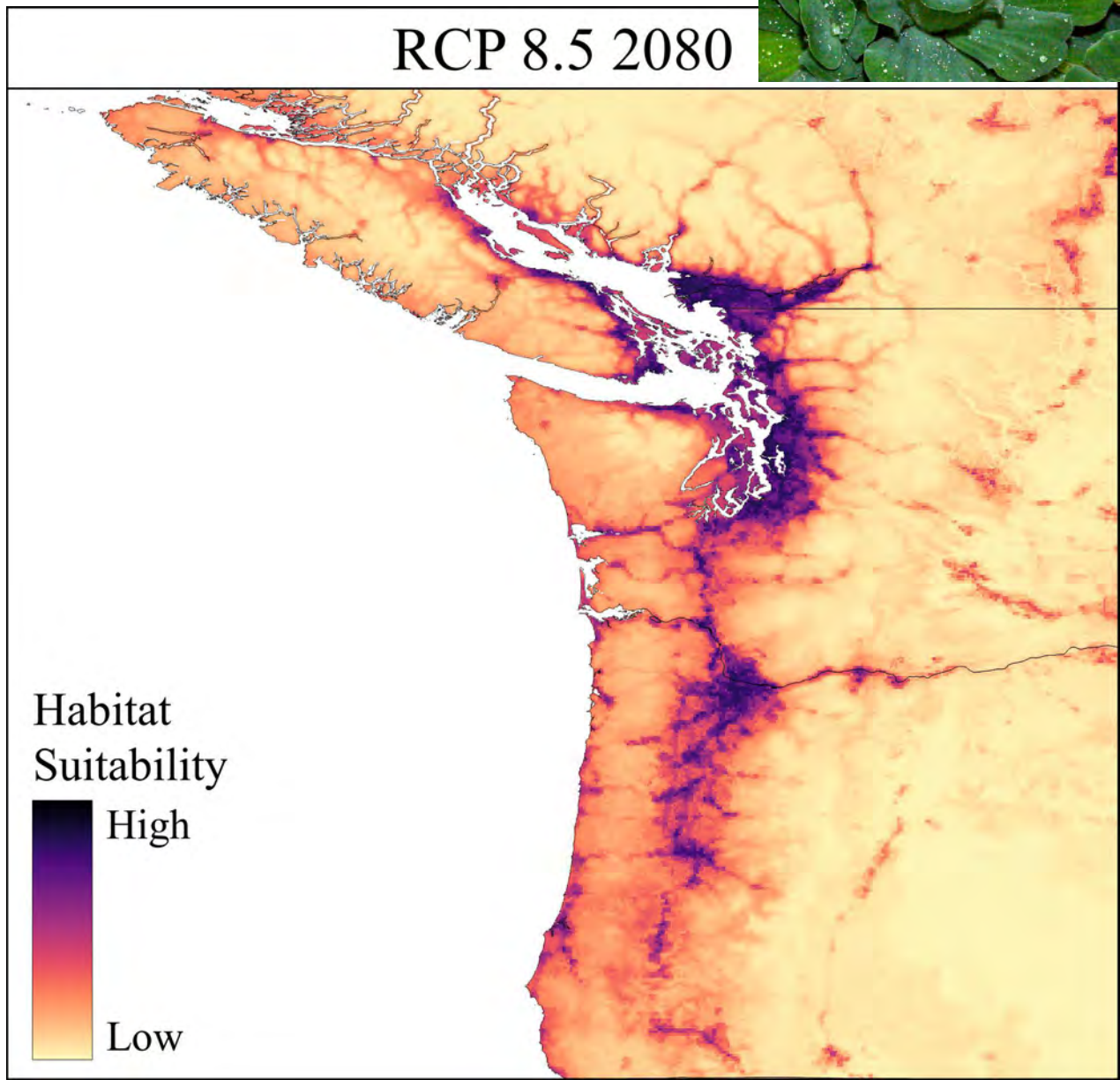
Pistia stratiotes

- pantropical aquatic native to both New and Old World tropics
- less likely to survive cold winters than water hyacinth with a higher minimum temperature 15 vs. 11 °C (McIsaac et al. 2016, *Hydrobiologia*)

Photo by Kurt Stüber

Water lettuce habitat suitability in the Pacific Northwest according to our ensemble modelling



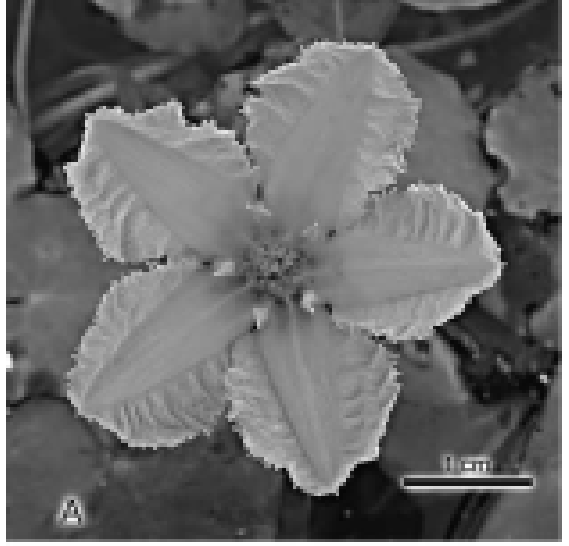


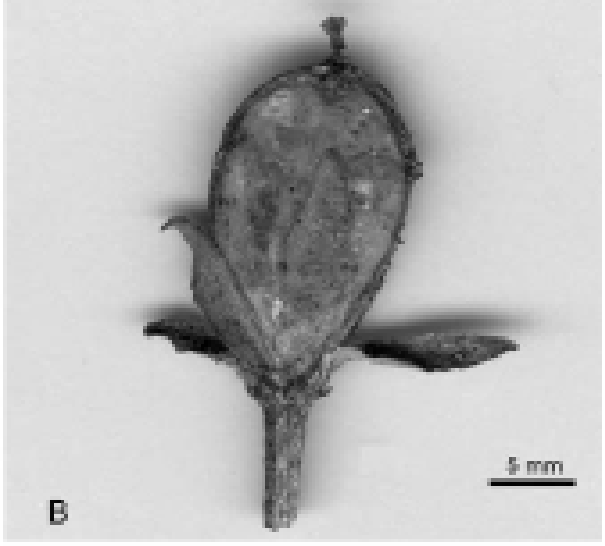
Yellow Floating Heart
Nymphoides peltatum

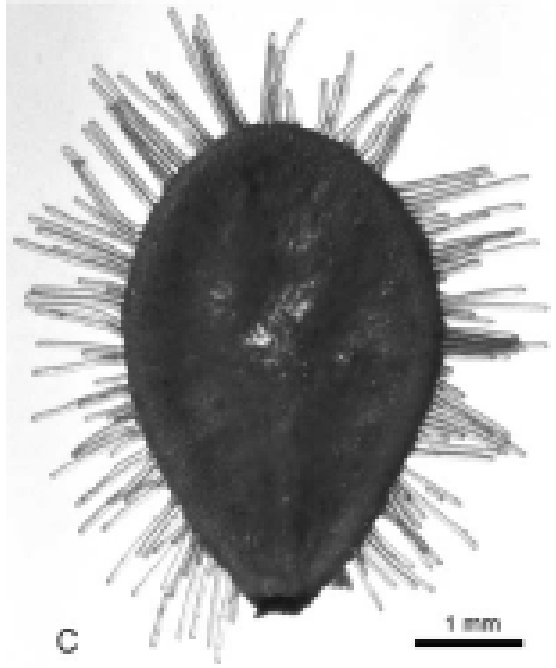
- native to Eurasia, the Mediterranean, south and east Asia
- overwinters as dormant, tuberous rhizomes
- range can extend to 60 °N latitude (=northern border of BC)

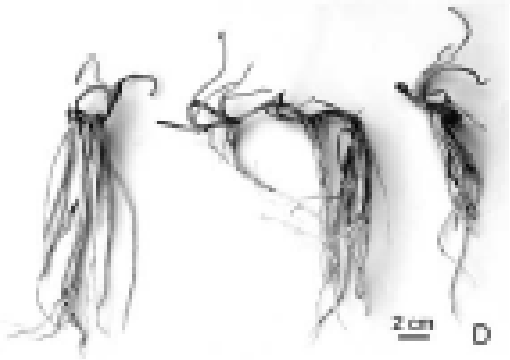
Fig. 1. *Nymphoides peltata* from Hallier (1884).

Fig. 2. *Nymphoides peltata* at Ottawa, ON. (A) Flower showing five fringed petals, five stamens, hairy staminodes and lobed stigma; (B) Mature fruiting capsule; (C) Seed showing fringe of translucent hairs; (D) Short rhizomes, stolons and roots of over-wintered plants collected 2006 Apr. 18, prior to spring flooding of pond; (E) Rafting seedlings among floating leaves and other emergent vegetation, 2000 May 21.









Darbyshire and Francis (2008) *Can J Plant Sci*

E-Flora BC Distribution Map

Nymphoides peltata (fringed waterlilly)

Gulf of Alaska

British Columbia

Alberta

Queen Charlotte Sound

Edmonton

Calgary

Vancouver

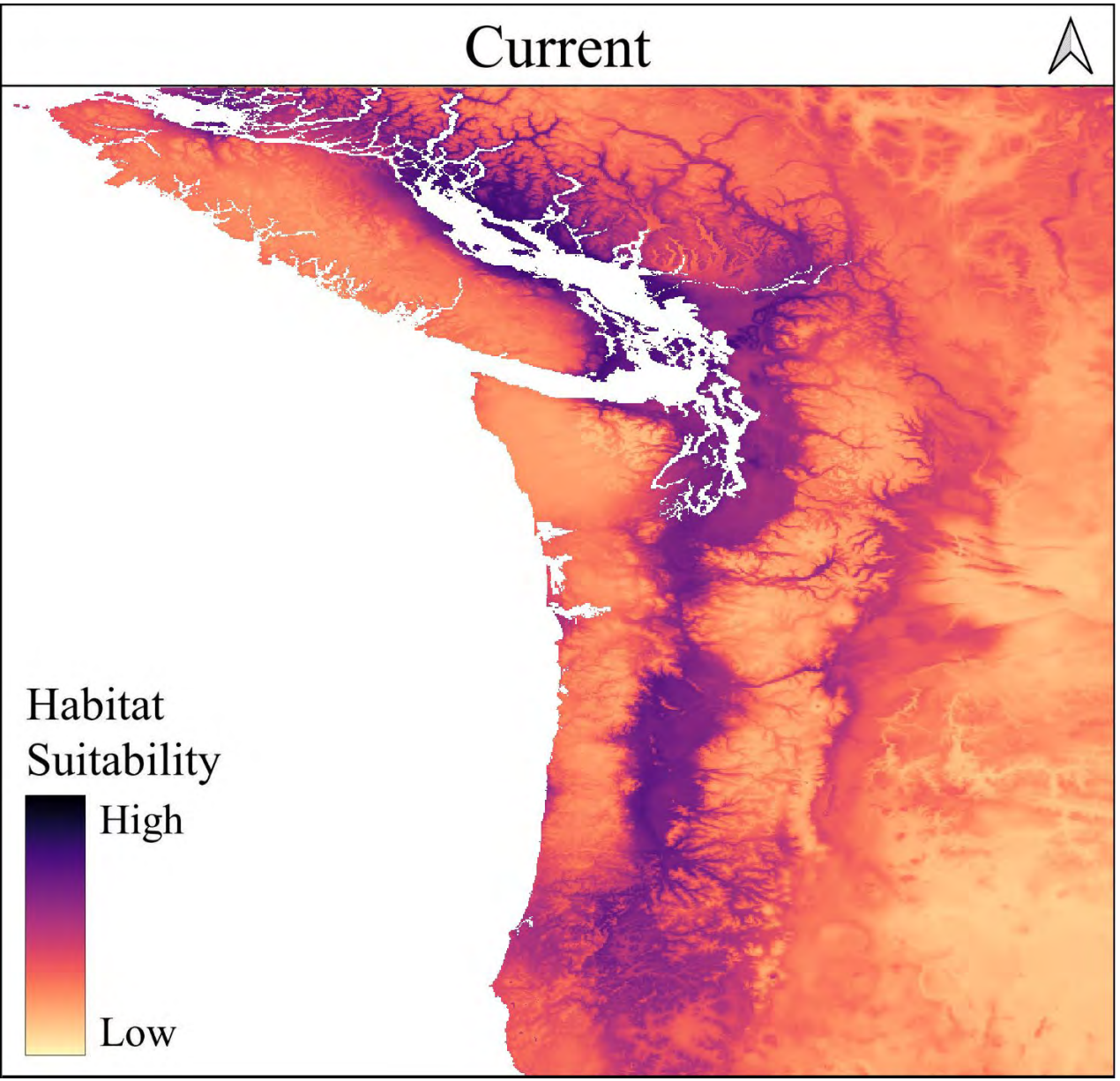
Seattle

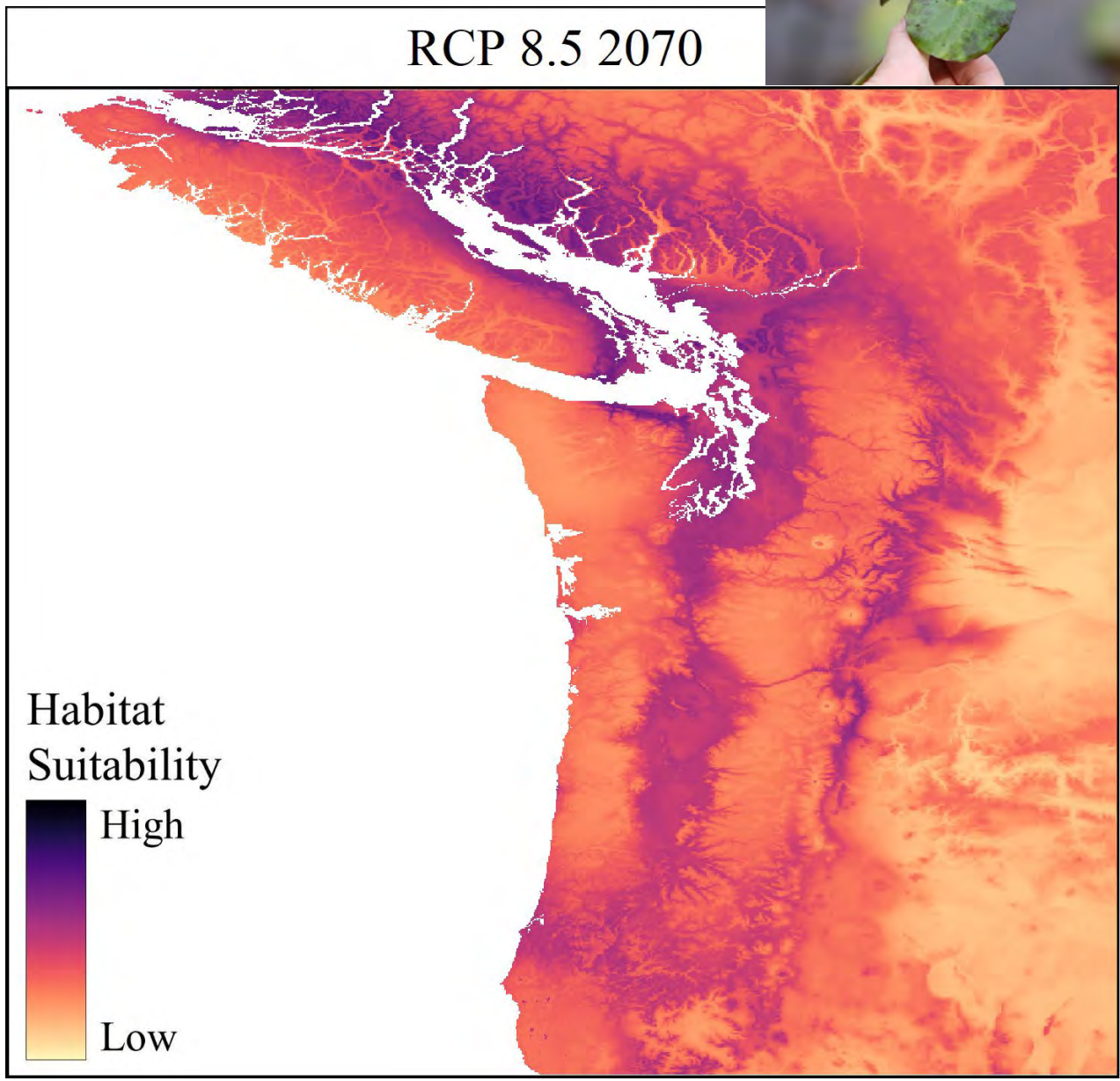
300 km

300 mi

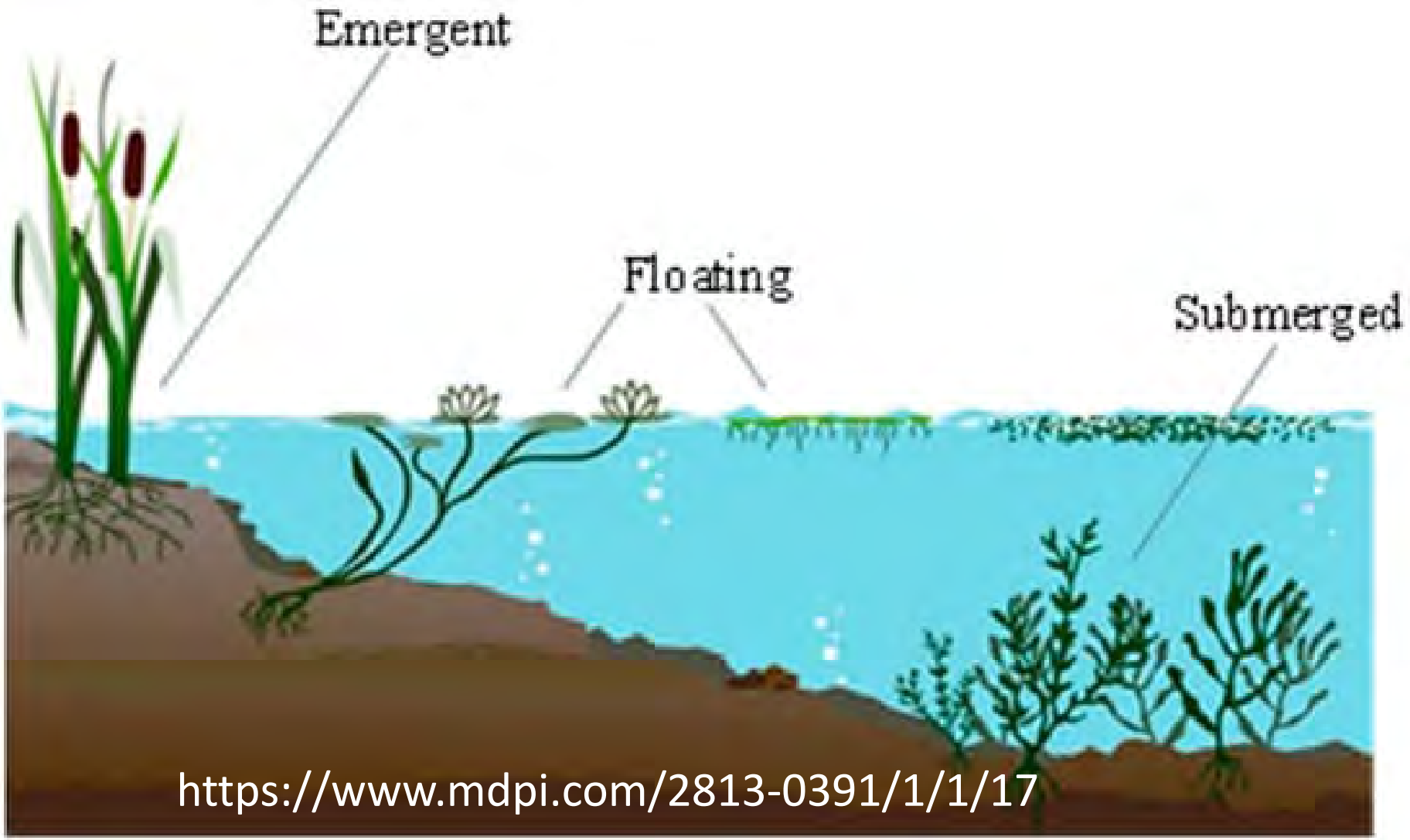

Detention pond in South Surrey, BC

Yellow floating heart habitat suitability in the Pacific Northwest according to our ensemble modelling





Emergent aquatic species



https://www.mdpi.com/2813-0391/1/1/17

Parrot's Feather

Myriophyllum aquaticum

- native to South America
- spreading globally through the tropics, subtropics and also occasionally in temperate zones
- although sensitive to freezing may overwinter in some northern latitudes (e.g., North England)
- thrives in wetlands with fluctuating water levels

Waterway in Richmond, BC

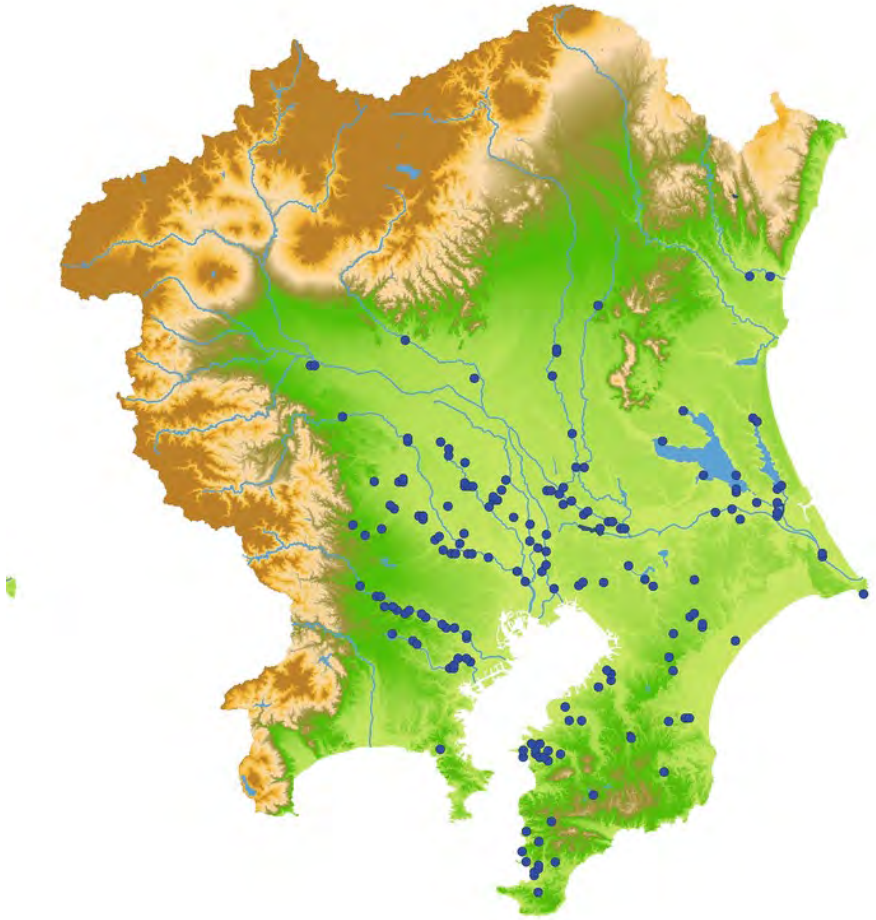
Photo by Leslie J. Mehrhoff

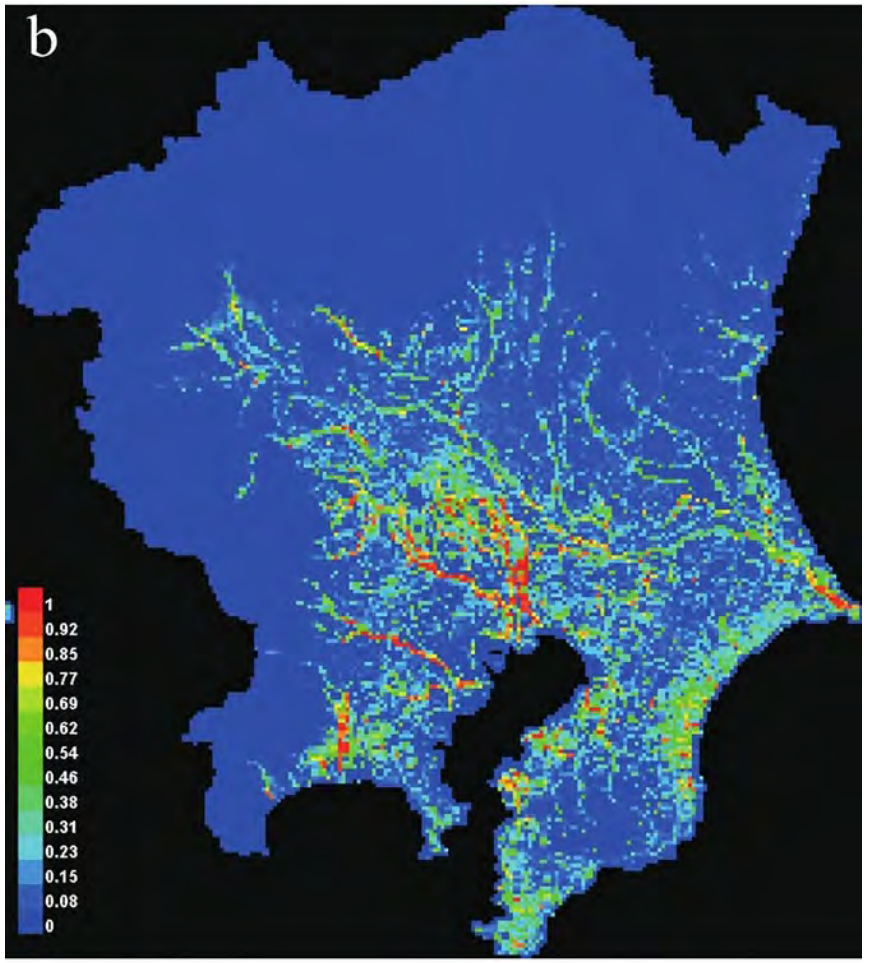
E-Flora BC Distribution Map

Myriophyllum aquaticum (parrot's feather)

Katzie Slough, Pitt Meadows, BC
Photo by Susanne Sloboda

Potential expansion of parrot's feather in the Kanto Region of Japan





MaxEnt modelling for current conditions, not incorporating climate change
(Yasuno 2022; *Landscape and Ecological Engineering*)

Flowering rush

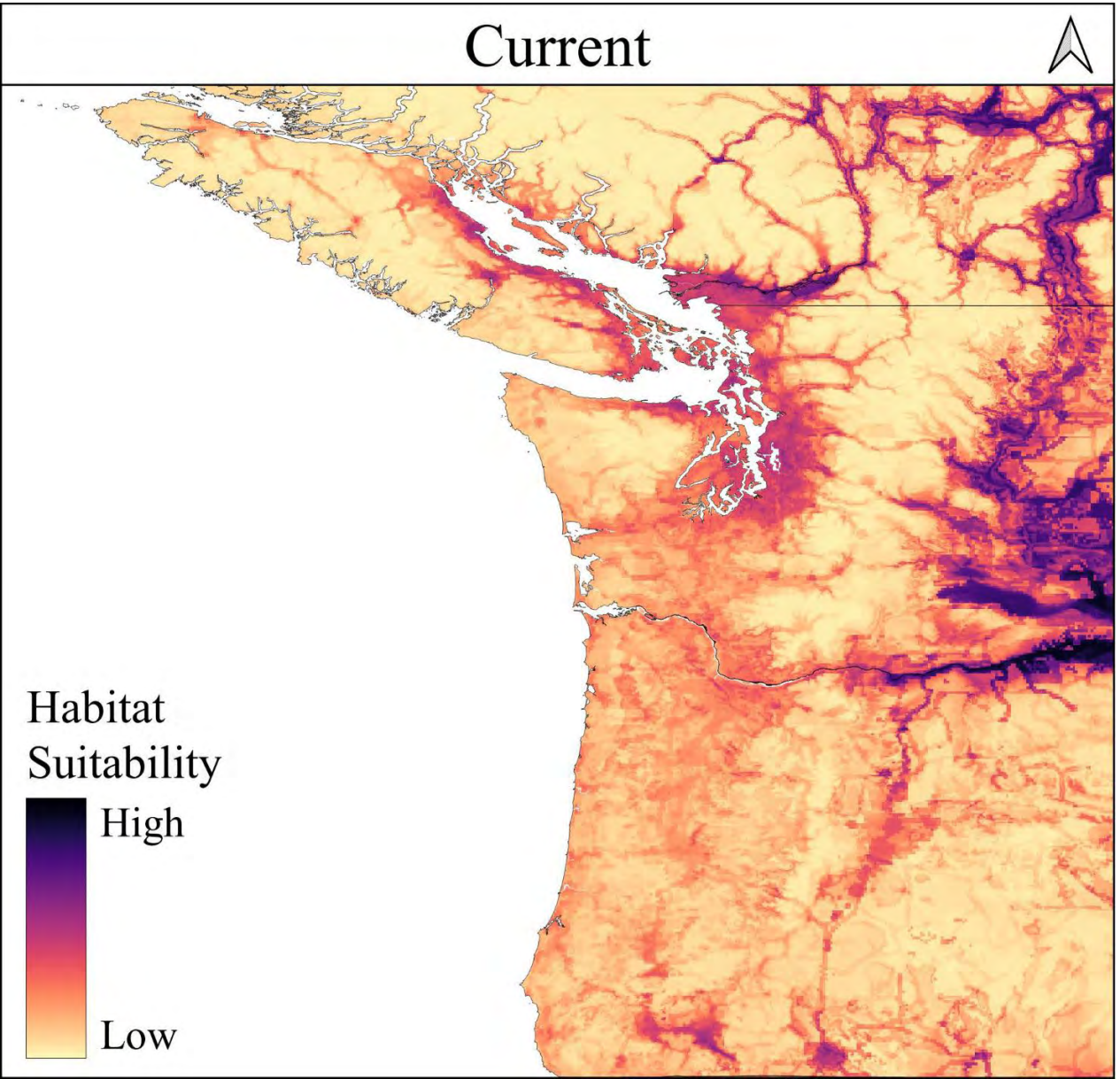
Butomus umbellatus

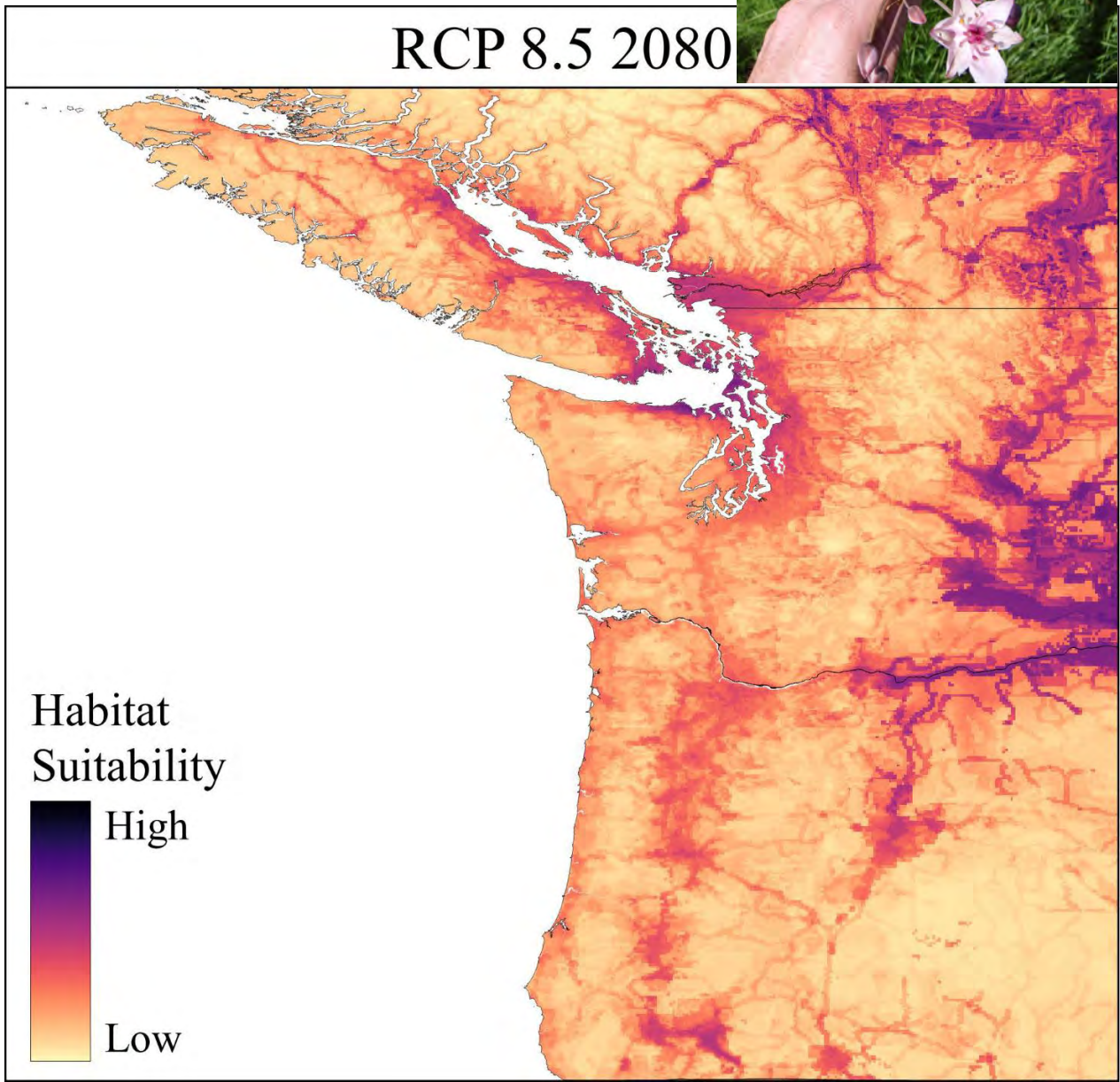
- native to Eurasia
- can grow submerged or emergent
- tolerant of fluctuating water levels and a wide range of temperatures
- prefers continental climates with contrasting seasonal conditions

Strathcona County, Alberta

Central Kootenay Invasive Species Society

Flowering rush habitat suitability in the Pacific Northwest according to our ensemble modelling





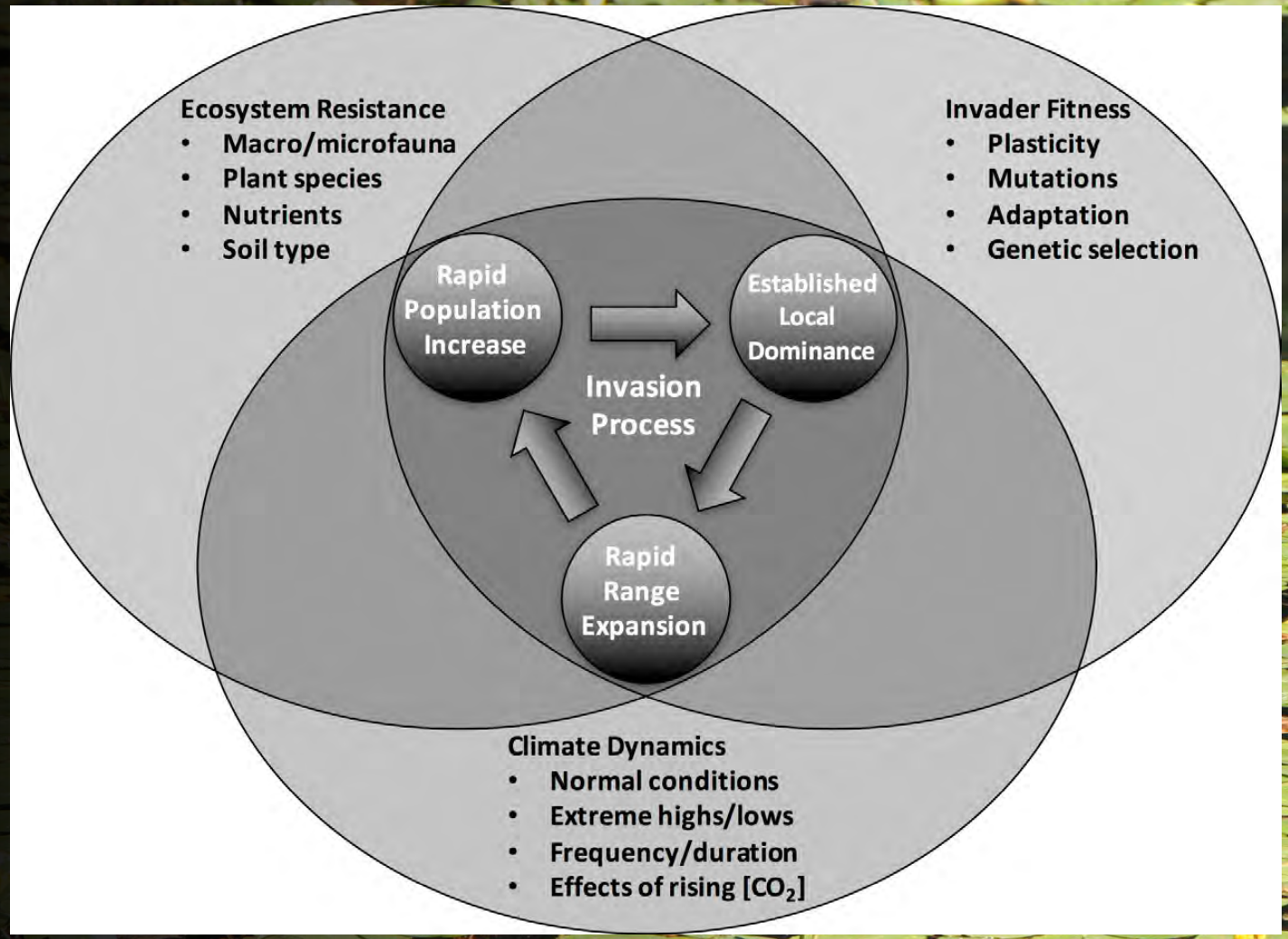
E-Flora BC Distribution Map

butomus umbellatus (flowering-rush)

Becky Brown, BC Invasive Plant Specialist at Hatzic Lake discussing flowering rush with Abbotsford MLA Simon Gibson (2016)

Aquatic invasions with increased flooding under climate change

- More widespread and frequent invasion could lead to improved invader fitness
- More frequent extreme events may reduce ecosystem resistance, harming the health of waterways
- Climate change mitigation must include monitoring and managing invasive plants



Acknowledgements

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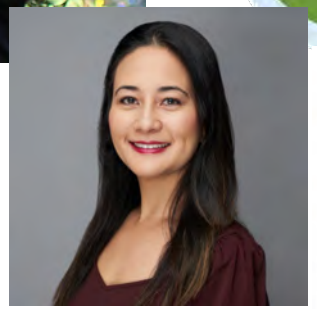

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Maria Goncharova

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- Outreach at the 2023 Chilliwack Run for Salmon, Saturday, Sept. 23, 2023